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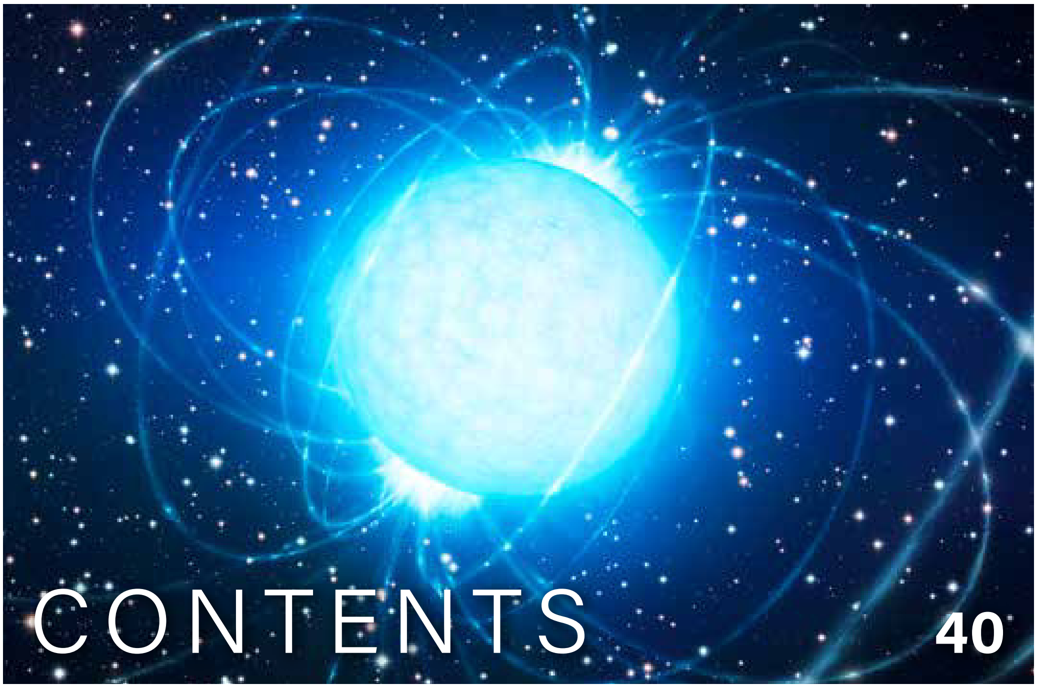

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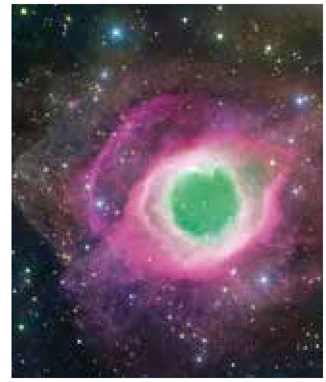

ON THE COVER

The James Webb Space Telescope will unlock secrets of star and galaxy formation, extrasolar planets, and more. Pictured is the Helix Nebula. CFHT, COELUM, MEGACAM, J.-C. CUILLANDRE (CFHT) & G. A. ANSELMI (COELUM)

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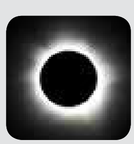

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Whaddya think of UFOs?

An alleged UFO hovering over Meersburg, Germany, is one of countless hoax images created.
WIKIMEDIA COMMONS

In response to the recent uptick in reporting about the subject, and the U.S. government investigations, I jotted down a few thoughts about this subject. As you undoubtedly know, it's frequently on the minds of observers of the sky. How much life is out there in the cosmos? Are any strange things we've seen in the sky evidence of physical visitation by other intelligent life?

To scientists, the recent surge in reports and news of governments spending lots of money investigating UFOs are curious. Astrophysicists know that the universe is incredibly large, with at least 100 billion galaxies, and several hundred billion star systems like our Sun's family in each one. We also know through spectroscopy that chemistry in the universe is consistent everywhere. That suggests that life should be common in the universe, although we have only one place where we know it exists — right here on Earth.

But the distance scale to even the nearest stars is incredibly vast. And the energy required to travel between star systems would be enormous, regardless of the technology, due to the known laws and limits of physics we understand very well (thanks to Newton, Einstein, and others).

This is a moment where wishful thinking enters for many: "But we don't know everything, so much of what we now know might turn out to be false." Some 2,000 years ago, Eratosthenes demonstrated Earth is a globe. Many could have then said that he didn't know what he was talking about and that might one day could be overturned. But mathematics, the language of the cosmos, works.

So it seems very likely that traveling between star systems would be an incredibly steep challenge for any civilization.

It may well be that reports of UFOs tell us more about the nature of people here on our planet rather than any potential advanced life forms that may exist in deep space.

Yours truly,

David J. Eicher
Editor

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Comet observers

In their "Comet Search" section of the June Sky This Month column, Martin Ratcliff and Alister Ling noted comet 7P/Pons-Winnecke's extremely close approach to the Earth in 1927, to within 0.04 AU. At about that time, astronomer Vesto Slipher trained Lowell Observatory's 24-inch Clark refractor on 7P and espied a "perfectly stellar" nucleus in excellent seeing conditions with the comet nearly overhead. To determine its size, he compared stars of similar brightness near Jupiter with the disks of its Galilean satellites.

In *Lowell Observatory Bulletin* No. 86, he reported, "The disks … appeared large and were estimated at fully ten times the linear diameter of the comet's nucleus." From this he concluded "that the nucleus of the comet was not more than two or three miles in diameter." Although Slipher's estimate was only semi-quantitative, it was the first to indicate the truly small sizes of typical cometary nuclei. This was fully demonstrated only much later by reconnaissance spacecraft and technically advanced Earth-based observations.
— Joseph N. Marcus, St. Louis, MO


GERALD RHEMANN

Comet 7P/Pons-Winnecke, captured on June 6, 2021.

Disappearing act

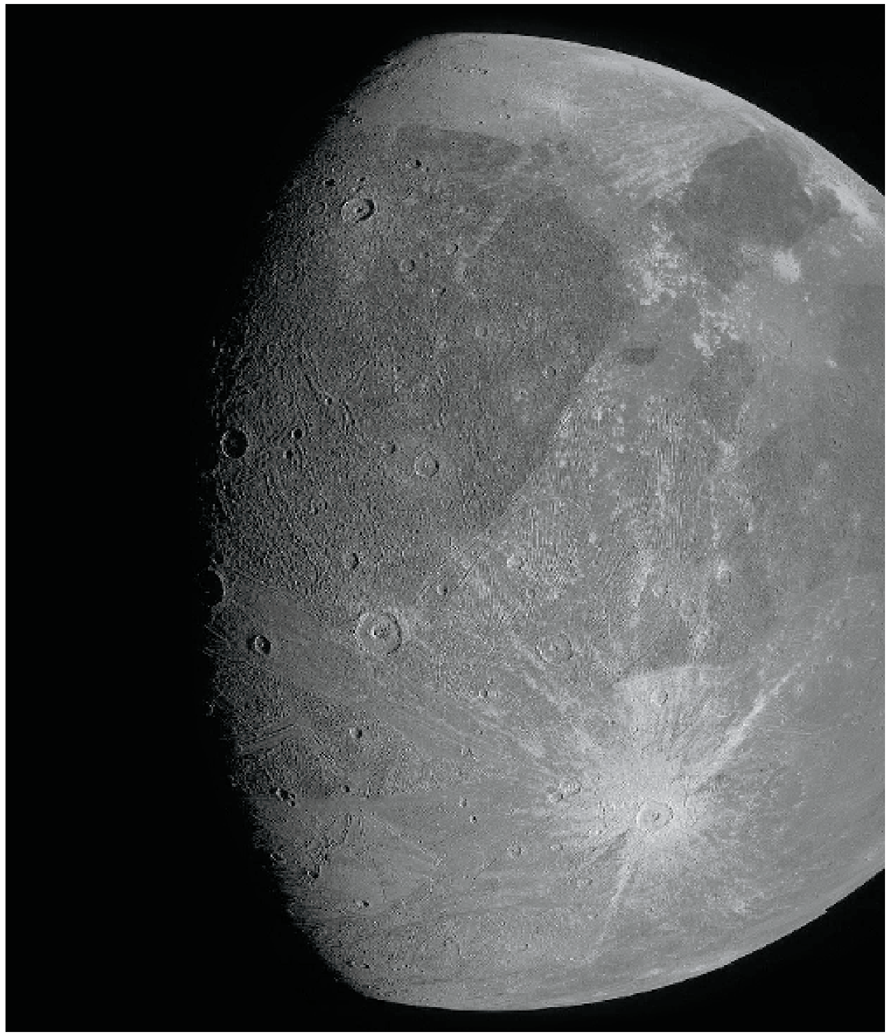
Thank you for your article on the canals of Mars as seen and mapped by Schiaparelli and P. Lowell. I was born in 1929, so I understood as a youth that the canals on Mars really existed. More recently we discovered that they certainly do not. But I understand to some extent the experiences of Schiaparelli and Lowell.

A few astronomers have suggested that the "canal mappers saw what they wanted to see." I disagree. I think, as your article suggested, the non-existing lines arise from the optics of one's eyes, in combination with the complex functions of our central nervous system, especially the brain. I'm rather pleased that I have something in common with the two notable astronomers Schiaparelli and Lowell! **— James A. Lewis,** Merrill, WI

SNAPSHOT

JUPITER'S MAMMOTH MOON

Ganymede's icy beauty is captured in new images from Juno.



NASA's Juno orbiter snagged new shots of the solar system's largest moon on June 7, 2021, during the closest flyby of Ganymede in two decades, at a distance of only 645 miles (1,038 kilometers). For comparison, the International Space Station orbits Earth at an average altitude of 250 miles (402 km).

Juno captured almost one entire side of Ganymede using the green filter on its visible-light imager, revealing the moon's craters and tectonic faults in intricate detail.

Scientists hope that these pictures, along with Juno's other measurements, will shed more light on Ganymede's composition and atmosphere.
—HAILEY ROSE MCLAUGHLIN

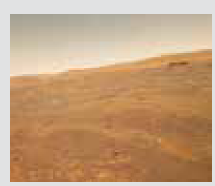
Mission scientists also compiled Juno's haul of images into a video showing the craft's perspective as it flew past Ganymede then swooped around Jupiter, spying the swirling gas bands that encircle the gas giant. Scan this code with your phone to view the animation.

NASA/JPL-CALTECH/SWRI/MSSS, BOTTOM FROM LEFT: CNSA; NASA/JPL-CALTECH; CARL KNOX, OZGRAV-SWINBURNE UNIVERSITY

» HOT BYTES

ORBITAL HOUSEWARMING

China's Shenzhou-12 spacecraft soared into space on June 17 Beijing time, ferrying a crew of three taikonauts to the country's fledgling Tiangong space station for the first time. The station is expected to serve as an orbiting laboratory for at least the next decade.



PERCY'S JOURNEY BEGINS

NASA's Perseverance rover kicked off its first martian science campaign on June 1. After months of systems tests and supporting test flights of the Ingenuity helicopter, Perseverance is setting out to search for signs of ancient microbial life in Jezero Crater.

ELUSIVE MERGER

After detecting both binary black hole mergers and neutron star mergers, LIGO has finally completed a hat trick by spying a black hole-neutron star merger. Researchers recently announced they had spotted gravitational waves from two such events in January 2020.

NASA, ESA TO RETURN TO VENUS

Three probes will voyage to our sister planet by the early 2030s.

VENUSIAN TRIO. Venus, seen here in a composite image from the Magellan and Pioneer Venus Orbiter missions, is the future destination of three new missions: two from NASA and one from ESA. NASA/JPL-CALTECH

» After leaving Venus in relative neglect for almost three decades, the U.S. and Europe are gearing up to mount a set of robotic expeditions that will give us our most comprehensive view yet of Earth's acidic sister.

On June 2, NASA administrator Bill Nelson announced the agency would send two new missions to Earth's inner neighbor by 2030. One of them, DAVINCI+, is a probe that will fall through Venus' atmosphere, sampling its caustic clouds and snapping closeups of its terrain. The other, VERITAS, will study the planet from orbit with state-of-the-art radar and imagers.

Eight days after NASA's statement, the European Space Agency (ESA) announced it had greenlit EnVision, another orbiter that will arrive at Venus in the early 2030s to study both its surface and its oppressive atmosphere.

The news thrilled many in the planetary science community who have been clamoring for decades for a renewed focus on Venus and its geology. The last NASA mission to target the planet was the Magellan probe, which orbited Venus from 1990 to 1994. Although the hellish world often serves as a flyby waypoint for spacecraft seeking a gravitational slingshot to more distant locales, its only dedicated visitors in the last 27 years have been ESA's Venus Express and Japan's Akatsuki (or "Dawn"), both of which studied the planet's atmosphere.

NASA's decision to double down on Venus surprised even the mission teams. DAVINCI+ and VERITAS were competing in a pool of four proposals under NASA's program of low-budget ($500 million) Discovery-class missions. NASA had said it would approve up to two proposals.

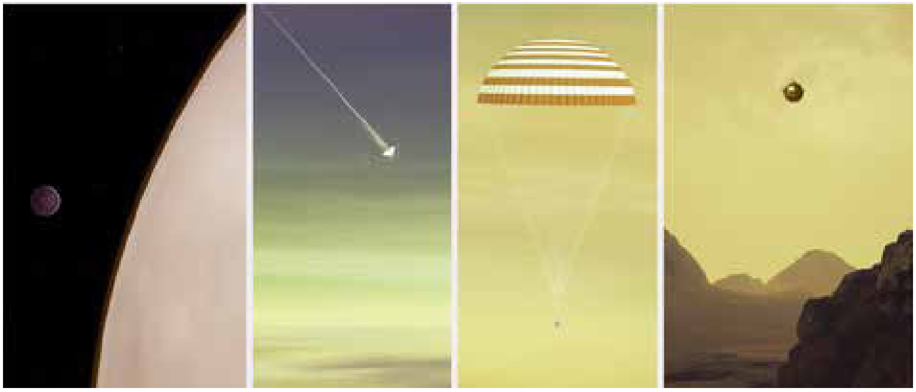
"Everyone hoped that one of the two slots would be a Venus mission," says Justin Filiberto, a member of the DAVINCI+ team and a geochemist at the Lunar and Planetary Institute in Houston. But choosing both, he says, "is incredible because it makes a mini Venus exploration program."

DAVINCI+ is short for Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging; the plus sign was added when the mission's proposal was revised and enhanced in 2019. VERITAS' full name is Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy.

COMPLEMENTARY CRAFT

While Venus has long taken a backseat to Mars in planetary exploration, over the past few decades, scientists have come to realize that the landscape beneath Venus' perpetual layer of clouds could once have been similar to Earth's — and perhaps even supported life. A major objective of the new missions will be to understand why these planets' fates diverged. And one major reason for scientists' excitement is that the trio of craft complement each other's capabilities.

When DAVINCI+ hits the venusian cloud tops, it will become the first



FREE FALL. When DAVINCI+ (above) enters Venus' atmosphere, it will initially use a parachute to slow down before jettisoning it and falling to the surface. NASA GSFC VISUALIZATION AND CI LABS MICHAEL LENTZ AND COLLEAGUES

SNEAK PEEK. VERITAS (left) will use its radar to peer below the clouds and reveal the surface of Venus in unprecedented detail. NASA/JPL-CALTECH

NASA mission to directly probe Venus' atmosphere since 1978, and the first from any nation since the USSR's Vega missions in 1985. As it falls, it will piece together a complete profile of Venus' atmosphere, layer by layer.

It will also sniff out interesting compounds — perhaps even phosphine, which was detected by radio astronomers last year to much fanfare. On Earth, phosphine is thought to be produced in large quantities only by microbes, which led the team to float the possibility that Venus' clouds could harbor life. However, after a data-processing error was discovered, the team decreased its estimate of phosphine levels, opening the door to other interesting geochemical processes that could explain what's occurring in Venus' extreme atmosphere.

Although DAVINCI+ is not designed to survive its hard landing on the surface of Venus, it will send images of the terrain from below the cloud deck as it descends toward the Alpha Regio highlands. Scientists hope to learn whether the rocks in the region — an area roughly twice the size of Texas — are made of continental granite or volcanic basalt. Granite would imply that water was present in the interior of Venus, while basalt can be produced without water. "So that tells a very different story about habitability," says Filiberto.

Meanwhile, from orbit, VERITAS will try to decipher Venus' surface geology with radar, and probe its interior by measuring the planet's gravity field. EnVision will study Venus' surface and atmosphere with European-built spectrometers, as well as look just beneath the surface with a ground-penetrating radar sounder. It will also carry a radar built by NASA's Jet Propulsion Laboratory, which is managing VERITAS. Together, the two craft will provide a global picture of Venus, from its clouds to its core. They might even spot changes in volcanoes and their lava flows since Magellan and Venus Express visited.

There could even be more spacecraft joining the party soon — Russia and India are separately planning their own Venus missions. As Filiberto notes, "Venus might get crowded in the next decade." —MARK ZASTROW

QUICK TAKES

FROM ERRORS, DATA

Cosmic rays — radiation in the form of atomic nuclei moving at near light speed — regularly zip through satellite computers, causing errors. By combing through 15 years of error logs from ESA's Rosetta and Mars Express probes, researchers found that increased solar activity results in fewer cosmic rays penetrating the solar system.

WATER, WATER EVERYWHERE

New calculations suggest liquid water can exist on the surfaces of moons of free-floating planets — worlds with no host star. Under certain conditions, cosmic rays and tidal forces can melt water on these moons in quantities large enough to support life.

DARK MATTER'S A DRAG

The rotation of the Milky Way's central bar has slowed by more than 24 percent since it formed, according to an analysis of the ages of stars within the bar. The galaxy's dark matter halo appears to act as a gravitational counterweight to the bar's rotation.

BLINKING GIANT

Astronomers analyzing archival data have uncovered a giant star that nearly disappeared from the sky for several months in 2012, dimming by a factor of 30. Dubbed VVV-WIT-08 (WIT stands for "what is this?"), the object may be a new class of star eclipsed by a companion object with an extended disk.

DEEP NOTES

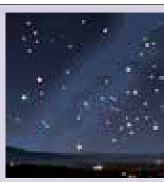
Rocket launches can be heard up to 5,600 miles (9,000 km) away by infrasound sensors designed to detect nuclear tests. Unlike most infrasound sources, the times of rocket launches are well known, which could make them useful for studying how infrasound propagates through the atmosphere. —M.Z.

THE BORTLE DARK-SKY SCALE

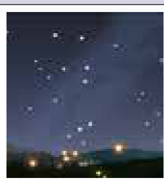
SEEING CLEARLY. Pollution from artificial lights profoundly impacts our view of the skies. Developed in 2001 by amateur astronomer John E. Bortle, the Bortle dark-sky scale runs from 1 (best) to 9 (worst) to rate the quality of the night sky's darkness. —ALISON KLESMAN

1. Excellent dark-sky site The Milky Way, zodiacal light, zodiacal band, and gegenschein are visible and often striking.
M33: Easily visible with direct vision
Naked-eye limit: magnitude 7.6–8
Telescopic limit (12.5-inch): magnitude 17.5

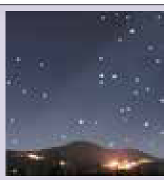
2. Typical truly dark site The Milky Way and zodiacal light still appear complex and colored.
M33: Visible with direct vision
Naked-eye limit: magnitude 7.1–7.5
Telescopic limit: magnitude 17



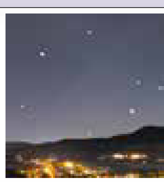
3. Rural sky Minor light pollution appears at the horizon, with the Milky Way and zodiacal light still clearly visible.
M33: Visible with averted vision
Naked-eye limit: magnitude 6.6–7
Telescopic limit: magnitude 16



4. Rural/suburban transition Light pollution is obvious around more heavily populated areas; the zodiacal light and Milky Way are visible but poor quality.
M33: Visible only with averted vision at high altitude
Naked-eye limit: magnitude 6.1–6.5
Telescopic limit: magnitude 15.5

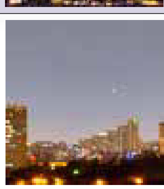


5. Suburban sky The sky is darker at the zenith than the horizon, where the zodiacal light and Milky Way are visible only under ideal conditions.
M31: Detectable as an oval-shaped glow
Naked-eye limit: magnitude 5.6–6
Telescopic limit: magnitude 14.5–15

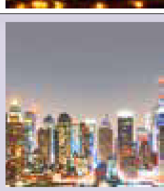


6. Bright suburban sky The horizon appears white or gray, hiding the zodiacal light. The zenith may show hints of the Milky Way.
M31: Visible as a faint smudge
Naked-eye limit: magnitude 5.5
Telescopic limit: magnitude 14–14.5

7. Suburban/urban transition The entire sky appears whitish-gray with little (if any) hint of the Milky Way.
M31: Rarely visible
Naked-eye limit: magnitude 5
Telescopic limit: magnitude 14



8. City sky The sky appears whitish-gray or orange, with only bright stars or planets visible. The Pleiades may be detectable.
M45: Likely visible
Naked-eye limit: magnitude 4.5
Telescopic limit: magnitude 13



9. Inner-city sky The entire sky is brightly lit, and only the Moon and brightest naked-eye planets and stars can be seen. Bright constellations are missing stars and dim constellations are invisible.
M45: May be visible
Naked-eye limit: magnitude 4

ASTRONOMY: ROEN KELLY

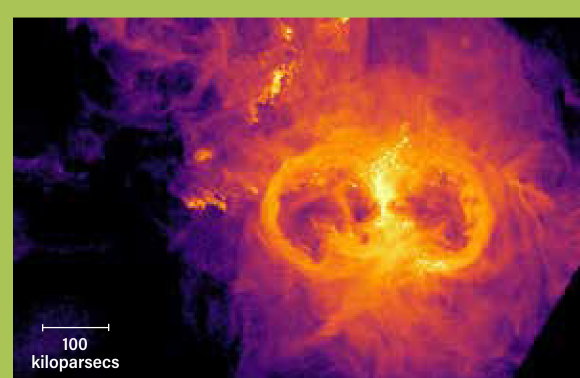
BLACK HOLES CAN BOOST STAR FORMATION IN SATELLITE GALAXIES

Astronomers have long observed that supermassive black holes lurking at the centers of galaxies can halt star formation. These behemoths blast their surroundings with high-energy radiation, disrupting clouds of potential star-forming material and heating them so they can't condense into new suns. But new research published June 9 in *Nature* paints a different picture. In some cases, supermassive black holes can instead facilitate star formation — not in the host galaxy, but in the small satellite galaxies that orbit their host galaxy.

The study looked at galaxies that are just joining a cluster. In such groups, the space between galaxies is filled with hot gas, called the intracluster medium. As a galaxy and its satellites move through the cluster, this gas acts like a headwind, stripping away star-forming material and slowing the birth rate of new stars. This is called quenching.

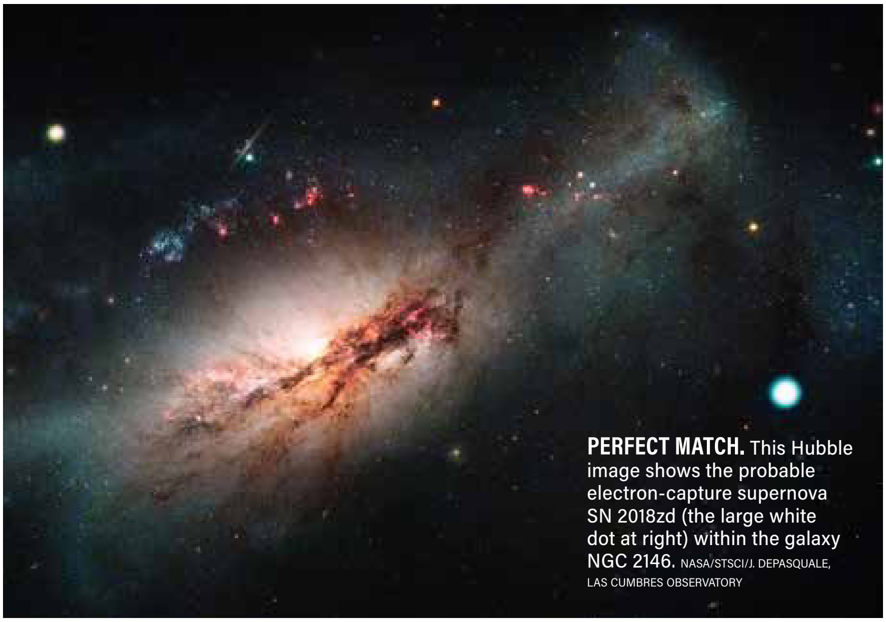
Researchers expected that when entering a cluster, satellite galaxies of a host galaxy with an active supermassive black hole should experience more quenching, as the black hole bombards the satellites with radiation and the intracluster medium strips away any remaining star-forming fuel. But observations of 30,000 galaxy groups and clusters showed that satellite galaxies orbiting above or below the plane of their host galaxy were actually 5 percent *less* likely to experience quenching. Simulations corroborated the find with similar outcomes.

The team believes the counterintuitive result occurs because the black hole's jets clear away some of the intracluster gas in a bubble around the galaxy and its satellites. Satellite galaxies in the right location within this bubble thus don't experience hot-gas headwinds, which in turn reduces quenching. The result demonstrates the profound influence of supermassive black holes on their environment. —A.K.



BLOWING BUBBLES. Supermassive black holes can carve out bubbles in hot intracluster gas, facilitating star formation in satellite galaxies within these regions. This snapshot from the TNG50 simulation shows a galaxy (yellow-orange, at center) whose black hole has carved out circular regions of low density in its surroundings (pink and purple). The scale of 100 kiloparsecs corresponds to about 326,000 light-years. TNG COLLABORATION/DYLAN NELSON

Third type of supernova explosion confirmed



PERFECT MATCH. This Hubble image shows the probable electron-capture supernova SN 2018zd (the large white dot at right) within the galaxy NGC 2146. NASA/STSCI/J. DEPASQUALE, LAS CUMBRES OBSERVATORY

WHEN YOU THINK OF A SUPERNOVA, the type you most likely imagine is a type II, or core-collapse, supernova. This type of cosmic blast happens when a star at least 10 times the mass of our Sun runs out of fuel and collapses at the end of its life, leaving behind either a neutron star or a black hole. The other type of supernova, type I, occurs when the remnant of a Sun-like star, called a white dwarf, siphons material from a nearby companion. Once it tips over a certain mass limit, a runaway thermonuclear explosion rips the white dwarf apart.

However, calculations dating back to 1980 show that there should be a third type of supernova, called an electron-capture supernova, that occurs only in stars in a narrow mass range: 8 to 10 solar masses. Before such a star can run out of fuel completely, magnesium and neon atoms that have piled up in its core begin capturing free-floating electrons around them. As these electrons are absorbed, the outward pressure holding up the star decreases and the star's inner regions collapse to a neutron star while the outer regions simultaneously blast outward as a supernova.

Now, for the first time, astronomers have confirmed one such supernova. The culprit, SN 2018zd, was spotted in the galaxy NGC 2146 in March 2018 by Japanese amateur astronomer Koichi Itagaki. The results are detailed in a paper published June 28 in *Nature Astronomy*.

The key was finding the progenitor star, which astronomers were able to do by looking at Hubble and Spitzer space telescope images of its host galaxy before and after the supernova. Both the star and the explosion fit expectations perfectly, matching all six expected criteria for an electron-capture supernova.

Now that researchers have solid evidence for this new type of supernova, they hope to use SN 2018zd as a template to identify other such blasts. For example, astronomers have long thought the supernova of A.D. 1054, which created the Crab Nebula (M1), was an electron-capture supernova. The confirmation of SN 2018zd provides the strongest evidence yet that this is the case. And finding more of these supernovae will reveal more about the galaxy and universe we inhabit, including how the deaths of massive stars fling the building blocks of life across the cosmos. —A.K.

NASA

FAILED ERUPTION FALLS BACK TO SUN

When the Sun is active, tendrils of hot plasma called prominences emerge from its surface. Energy from the Sun's magnetic field can build up in these coiled features, causing them to erupt into space. But on March 12 and 13, 2016, NASA's Solar Dynamics Observatory snapped this image of a failed eruption. Research presented June 7 at the American Astronomical Society's summer meeting shows that this prominence never gained enough energy to launch into space. Instead, it fizzled out, its plasma draining back to the Sun's surface. Solar physicists hope the event will help them understand why some eruptions result in narrow jets, others become powerful coronal mass ejections, and some simply wither away. —M.Z.

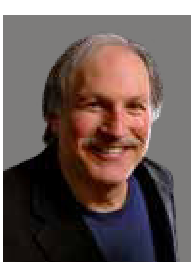
1,715

The number of nearby star systems within 326 light-years that could have spotted Earth over the last 5,000 years as it crossed in front of the Sun. Another 319 stars will enter this vantage point in the next 5,000 years.

Facing reality

What's in a Full Moon?

The Deep Space Climate Observatory's Earth Polychromatic Imaging Camera periodically views transits of the Moon across Earth. It snapped this pic July 16, 2015, showing just how dark the Moon is compared to our planet. NASA EPIC TEAM



BY BOB BERMAN
Bob's newest book, Earth-Shattering *(Little, Brown and Company, 2019), explores the greatest cataclysms that have shaken the universe.*

In the mass media, names like Blood Moon, Blue Moon, and Super Moon have replaced astronomers' traditional lunar designations. But all such ambiguity now temporarily vanishes. September's Harvest Moon and October's Hunter's Moon remain the only widely used Full Moon names — many almanacs routinely list those two but no others. Which makes this the perfect time to "get real" with the Full Moon.

In my decades of experience, it's the only nightly object known to everyone. This is certainly strange — that everyone recognizes the Moon but few can identify even a single other celestial object at night. (Of course, everyone can say, "That's a star," but few can tell you *which* star.) This isn't true in other areas of science or nature. People who can name one type of cloud can probably identify a few others, too. If you can point out a cardinal, you can likely also identify robins, pigeons, and crows. Only in the night sky does nearly everyone know exactly one object but no further examples.

The Moon is the only nightly object known to everyone.

So, let's use this widespread familiarity with the Full Moon to try to expand our friends' appreciation of the heavens. Given that they've seen the Moon all their lives, its basic visual qualities should be familiar. But, as we'll see, it's easy to have fun and astound others when it comes to asking a few simple questions about the Full Moon.

Its apparent size. Okay, how large is the Full Moon? Most folks aren't familiar with degrees and angles, so phrase it this way: "How many Full Moons would you need to pile one atop the other to stretch from the horizon to a point directly overhead?" Ask your family. Most will guess between 30 and 50 Moons.

You'll laugh when you survey a bunch of people because you'll keep hearing that same 30-to-50 range. The reality? You'd need 180 stacked Full Moons to fill that gap. The Moon is far smaller than people perceive.

Its brightness. Here's the next misconception: Ask, "How much dimmer is a scene lit by the Full Moon than a sunlit scene?" Their answer will now range from 100 to 1,000 times, meaning, people think sunlight is as much as a thousand times brighter than the Full Moon.

The real answer? Sunlight is 450,000 times brighter than the Full Moon.

Its shininess. The Moon looks dazzlingly white. Expressed as a percentage of the sunlight it reflects (its albedo) the Moon might seem to rate at least a 50 — as in, it is 50 percent reflective.

Textbooks, however, tell us that the average lunar albedo is 11. This is amazing and noteworthy. Dark forest foliage has an albedo of 15. Charcoal is 5. So, the Moon's surface reflectivity lies somewhere between coal and dark green leaves — super murky. Why does it seem so white and bright?

It's because the mammalian eye resets brightness levels according to your surroundings. The Full Moon hovers against a black background sky, so our brains paint it white. But what if we could somehow see it against an earthly background? Amazingly, NASA's Deep Space Climate Observatory (DSCOVR) accomplishes exactly that. Orbiting a million miles (1.6 million kilometers) from us at a Lagrange point where Earth's gravity balances the Sun's, it always views a Full Earth. Twice a year, DSCOVR's orbit aligns with the Moon's tilted orbital plane so that the spacecraft catches the Moon passing in front of Earth. Then, its images confirm that the Moon has one-quarter Earth's diameter. But even better, it then also shows that the Moon has about one-third our shininess, revealing that the Moon is a very dark object!

As a bonus, DSCOVR is peering at the lunar hemisphere facing away from Earth — the one that strangely has very few basaltic plains or maria, the dark blotches that dominate our own naked-eye lunar view. So it always sees the brightest lunar hemisphere. And yet, look at it! Here at last, after 2 million years of humans gazing moonward, preceded by just as many years when our lupine friends howled in its direction, we at last view the Moon against an earthly setting instead of a black sky. And we finally learn firsthand that the Moon is a miserably dim body.

This picture barely made a splash when NASA released it a few years ago. But let's now let it sink in: This is the true Moon. The actual dim, dark, desolate Moon. And the final nail in the coffin of the public's endless lunar misconceptions.

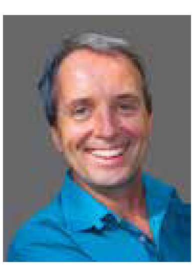
BROWSE THE "STRANGE UNIVERSE" ARCHIVE AT **www.Astronomy.com/Berman**

Catching Mercury by the tail

It's possible to capture this planet's glowing sodium tail without any filters or special equipment.

LEFT: STEPHEN JAMES O'MEARA. CENTER: ANDREA ALESSANDRINI. RIGHT: PAUL ROBINSON

1. Mercury (near center) shares a twilight sky with a waxing crescent Moon and Venus (lower left). **2.** Astrophotographer Andrea Alessandrini captured this image of Mercury's sodium tail as its brightness was peaking on May 13, 2021, through a 2.5-inch refractor. **3.** Paul Robinson used a 300mm lens on a Nikon D750 DSLR set at ISO 3200 to capture this stunning image of Mercury's tail without a special filter. The image is a composite of three 30-second exposures.



BY STEPHEN JAMES O'MEARA

Stephen is a globe-trotting observer who is always looking for the next great celestial event.

Since time immemorial, Mercury has been known but seldom seen. This diminutive world — only slightly larger than our Moon — never strays more than 28° from the Sun. We often see its modest light hugging the horizon with a pink countenance, as if blushing over its poor performance. But this "inferior" world has recently captured the attention of observers around the globe by revealing one of its long-kept secrets: Like a comet, Mercury sports a tail, one that can be captured by ordinary camera equipment. Who knew?

A tenuous tail

Mercury is surrounded by a tenuous atmosphere dominated by sodium. In the May 1986 issue of *Geophysical Research Letters*, Wing-Huen Ip of the Max-Planck-Institute for Aeronomy in Germany (now the Max Planck Institute for Solar System Research) theorized that radiation pressure from the solar wind could be strong enough to liberate sodium and other particles from the planet's surface. This would produce a long cometlike tail in the anti-solar direction, where the Sun's energy would cause the particles to glow.

Fourteen years later, Andrew Potter of the National Solar Observatory in Boulder, Colorado, and his colleagues used the 1.6-meter McMath-Pierce Solar Telescope to detect and map emission from the D2 sodium line. They found sodium atoms streaming from the planet out to a distance of 25,000 miles (40,000 kilometers), proving that sodium is imparted with sufficient energy to escape the planet and form its tail. Subsequent studies have found the tail extends at least 15 million miles (24 million km) from the planet.

Meeting the challenge

Last May, I received an email from Paul Robinson of Longmont, Colorado, alerting me to a startling fact: Mercury's sodium tail can be imaged with simple camera equipment. He first learned this from the website spaceweather.com in a Nov. 18, 2020, post. Then, on May 10, 2021, Tony Phillips wrote about how Andrea Alessandrini had photographed Mercury's tail from the balcony of his house in Veroli, Italy.

To capture the tail, Alessandrini attached his Pentax K3-II camera to his 2.5-inch guided refractor and took a seven-minute exposure at ISO 1000. The key to his success, he explained, was the additional use of a 589-nanometer filter tuned to the yellow glow of sodium. In the article, Alessandrini is quoted as saying, "Without that filter, Mercury's tail would be invisible."

These words caught Robinson's attention. "I tend to feel things are more visible [without filters] than people often think," he said. "So why not try?" The next day, Robinson did try, but without success. He found Mercury's orbital position and the twilight conditions under which he observed were less than ideal. Rather than change his belief, he changed his tactics.

As Mercury's tail is brightest within 16 days of the planet's perihelion passage (which occurred April 27 UT), he planned to try again on the nights of May 10–12, while vacationing in Flagstaff, Arizona, about a week prior to Mercury's greatest eastern elongation (May 17 UT). The best night occurred on the 12th, when, from Meteor Crater Road, he imaged Mercury at about 5° altitude in dim twilight, using "normal camera equipment and methods," and, of course, "no filter."

While he suspected he had achieved success, he did not verify it until he returned home and processed the images. The final shot, shown above, is a composite of three enhanced images and shows the warm-hued tail, ½° long.

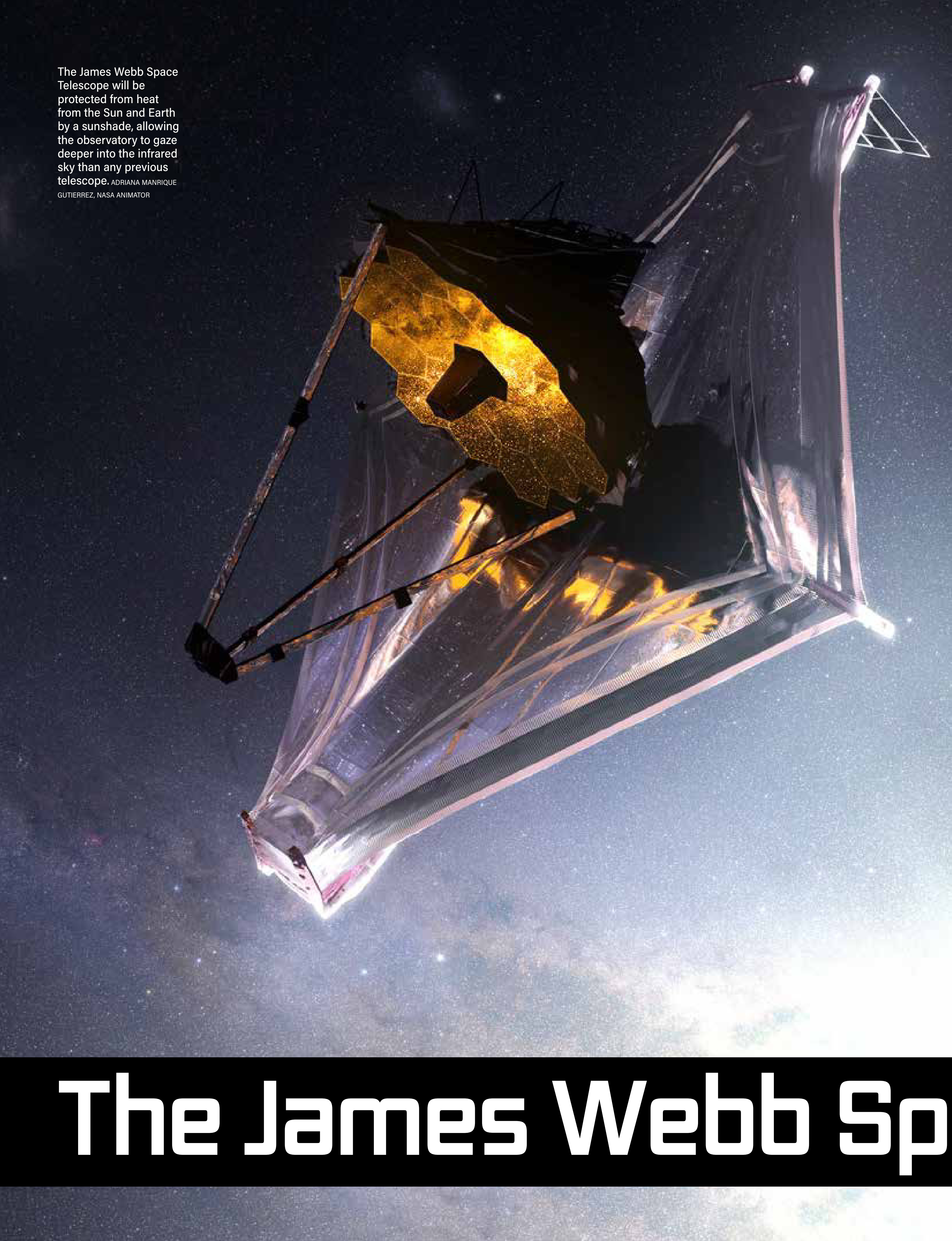
"I noted the tail pointed slightly north of lines parallel to the ecliptic, but Mercury was north of the ecliptic, so the angle was right! Also, it was a bit redder than the overexposed planet. I slightly suspect the possibility of an anti-tail [pointing sunward,] too."

A fortunate circumstance

This October, brings us another fantastic opportunity to capture Mercury's tail. Perihelion occurs on Oct. 20, which happens to be just five days before its greatest western elongation in the morning sky. "I actually suggest the week before (Oct. 17–25) as best for tail viewing, to take advantage of forward scattering of light and a more favorable Sun-Mercury-Earth geometry," Robinson says. "The planet will be dimmer then due to its thin crescent shape, but the tail brighter."

This "tail" of Mercury just may put an end to the planet's formerly inferior reputation and elevate it to the status of a first-class wonder. As always, send your thoughts and observations to sjomeara31@gmail.com.

BROWSE THE "SECRET SKY" ARCHIVE AT **www.Astronomy.com/OMeara**



The James Webb Space Telescope will be protected from heat from the Sun and Earth by a sunshade, allowing the observatory to gaze deeper into the infrared sky than any previous telescope. ADRIANA MANRIQUE GUTIERREZ, NASA ANIMATOR

The James Webb Sp

ace Telescope lives!

The most powerful space telescope ever built, NASA's new flagship observatory will look deeper than Hubble and hunt for neighboring life.

BY JOHN MATHER

How did the Big Bang make you and me possible? Are we alone, and how close are the neighbors? The vast, unexplored cosmos is fertile ground for astronomers' imaginations. And yet, almost every important discovery came as a surprise.

The James Webb Space Telescope (JWST), set to launch as soon as November, will attempt to answer these questions — and the ones we don't even know to ask yet. It will crack open the treasure chest of the magnificent infrared sky, invisible to human eyes. With its great golden 6.5-meter primary mirror and its suite of cameras and spectrometers, the Webb can sense light ranging from the middle of the visible spectrum to the mid-infrared. If there were a bumblebee hovering in space at the distance of the Moon, the Webb could see both the sunlight it reflects and the heat that it emits.

As the telescope's senior project scientist, I've been working with the JWST team since we started in 1995. Our discoveries will be released as they are for the Hubble Space Telescope (HST) — some immediately, some after more detailed analysis — and everyone will be able to download our images. We know where we will look, we can guess what we will find, and there will be surprises.

We will look back in time by looking far away to hunt for the first galaxies, the first stars, the first supernovae, and the first black holes. Having grown from the pure hydrogen and helium available in the early universe, these objects were very different from today's modern examples.

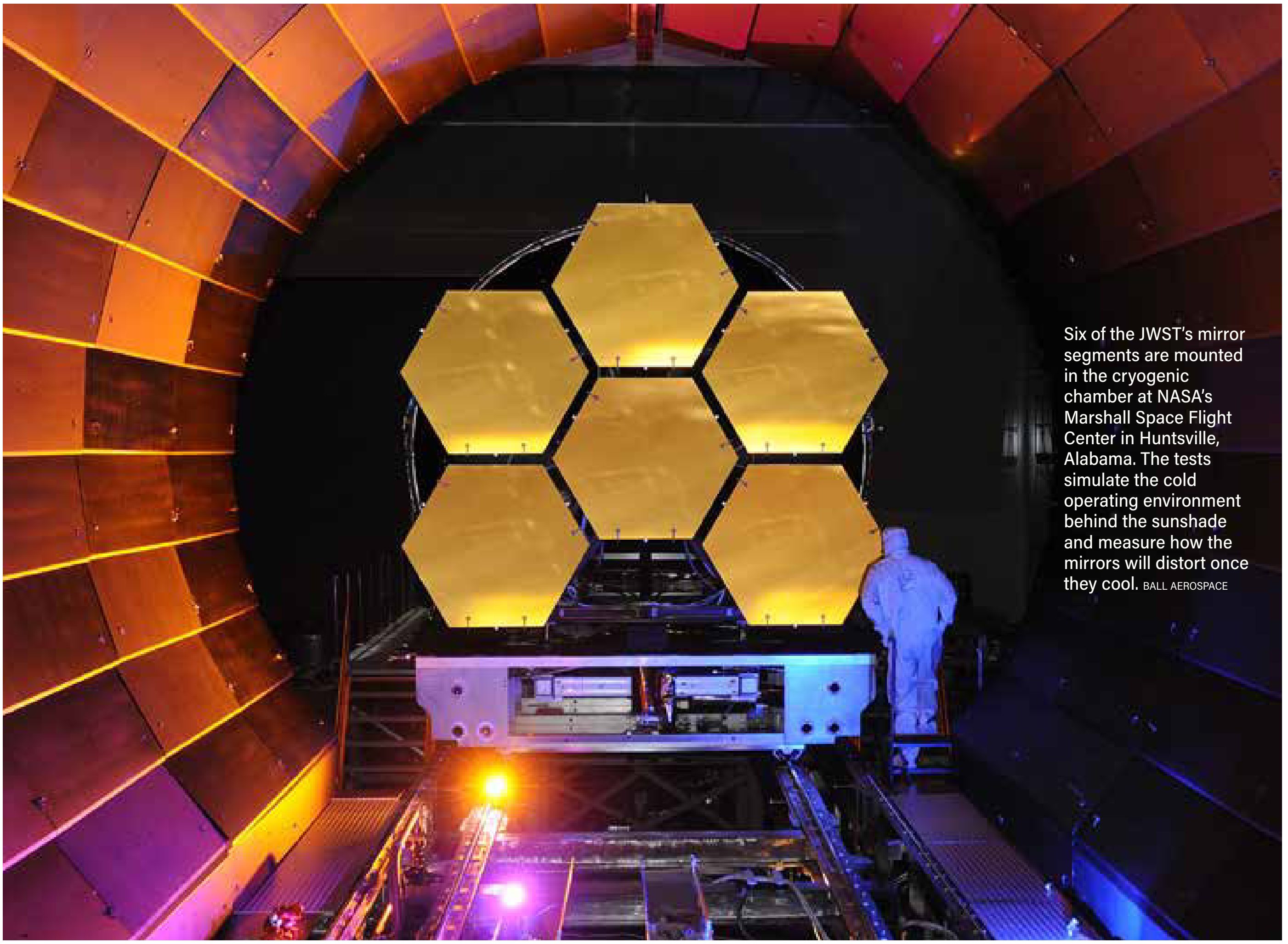
We will measure the effects of dark matter and dark energy, even though we can't see them. We will learn how galaxies grow by comparing young and old. We will watch new stars being born, looking inside the dusty clouds of gas, like the so-called Pillars of Creation, where they grow.

And we will ask how our solar system formed and how it evolved to support life. We will do this by looking at the planets and small bodies close to home, and by watching other solar systems. The infinite universe surely has life elsewhere, but where are the neighbors? If there are nearby exoplanets with liquid water, the JWST can find them.

Bigger and better

Even before the Hubble telescope was launched, astronomers met to consider its successor. In 1995, they produced a report titled "HST and Beyond," outlining the community's next steps. It proposed the concept and scientific requirements of what would become the JWST, and called for investment in the technology required to hunt for exoplanets similar to Earth.

Today, the Webb represents the culmination of a 25-year effort led by NASA with major contributions from the European and Canadian space agencies and a consortium of 14 European laboratories. The Space Telescope Science Institute (STScI) will operate Webb from Baltimore, where we are currently rehearsing every detail of the flight mission. Many thousands of engineers, scientists, technicians, managers, planners, accountants, and secretaries were on the teams that built it.



Six of the JWST's mirror segments are mounted in the cryogenic chamber at NASA's Marshall Space Flight Center in Huntsville, Alabama. The tests simulate the cold operating environment behind the sunshade and measure how the mirrors will distort once they cool. BALL AEROSPACE

The JWST extends and complements the capabilities and discoveries of the 2.4-meter Hubble Space Telescope and the pioneering 0.8-meter Spitzer Space Telescope. Spitzer was designed to see infrared but is now out of range of Earth; it was retired in January 2020.

Hubble is sensitive to a small portion of the infrared spectrum. But despite being in space, it is warm enough to glow at infrared wavelengths, which interferes with infrared observations.

Webb is not just a bigger version of Hubble: It will be kept cold, so it does not emit infrared radiation. That means that, unlike Hubble, the telescope cannot be enclosed — it must be open to space with its components exposed so it can maintain a low temperature without an active cooling system.

It also means the Webb cannot stay in low Earth orbit. Earth radiates heat that warms nearby satellites, and we could not find a design that would keep the Webb cold there. Instead, we will push the telescope out near the Sun-Earth L2 Lagrange point, which you can find by extending the line from the Sun to Earth 930,000 miles (1.5 million kilometers) farther. At this location, the combined gravity of the Sun and Earth will keep the Webb in an orbit around the L2 point. This is the nearest place to Earth where a single umbrella (called a sunshade) can protect the telescope from the heat of the Sun, Earth, and the Moon.

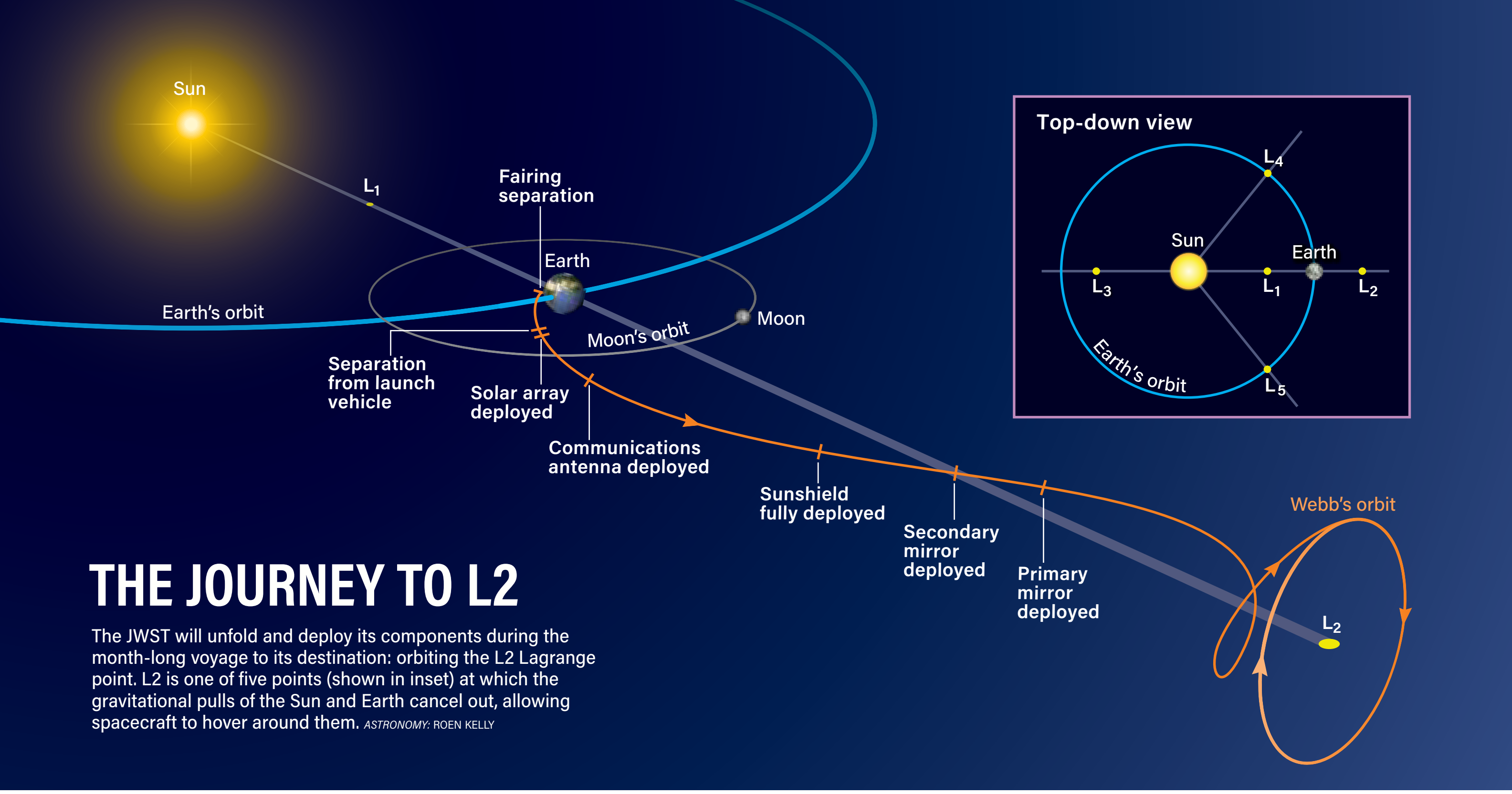
The JWST also must be much larger than Hubble because the targets it will observe are faint and far away. The Webb is so large that it must be folded up for launch, and even then, it barely fits inside the fairing of the Ariane 5 rocket. To allow for folding, the 6.5-meter-wide primary mirror had to be made of 18 smaller hexagons, which, once in place, will function as though they were one unit.

The whole package

JWST's instrument suite covers the whole infrared wavelength range — from 0.6 to 28.8 microns — with imaging cameras, spectrometers, and a fine-guidance camera. All the instruments are passively cooled to –387 degrees Fahrenheit (–233 degrees Celsius, or 40 kelvins). The exception is the Mid InfraRed Instrument (MIRI), a camera and spectrograph that requires active cooling to –447 F (–266 C, or 7 kelvins).

The Webb's Near Infrared Spectrometer (NIRSpec) can take spectra of 100 galaxies at a time by using tiny shutters that only let in the light from target objects and block everything else. Spectroscopy breaks light apart into its full spectrum like a prism, allowing us to identify different elements absorbing or emitting light at various wavelengths. From these spectral signatures, we can determine the chemical composition, the temperatures, and the motions of these targets. Spectroscopy puts the "fizz" in astrophysics.

The Near Infrared Camera (NIRCam), MIRI, and the Near Infrared Imaging



THE JOURNEY TO L2

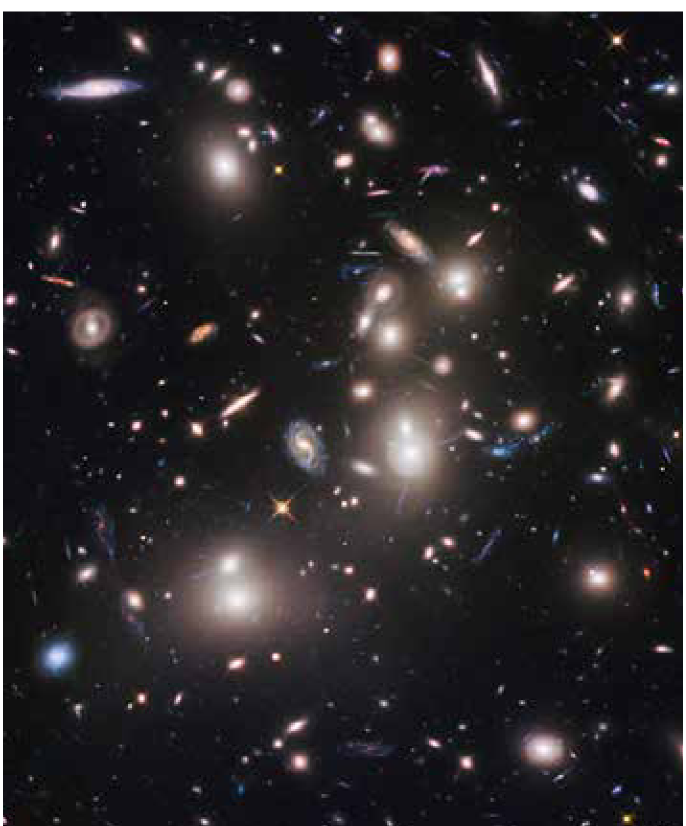
The JWST will unfold and deploy its components during the month-long voyage to its destination: orbiting the L2 Lagrange point. L2 is one of five points (shown in inset) at which the gravitational pulls of the Sun and Earth cancel out, allowing spacecraft to hover around them. *ASTRONOMY:* ROEN KELLY

Slitless Spectrometer (NIRISS) all have coronagraphic capabilities, meaning they can block the light of a bright star to look for orbiting exoplanets or blot out light from a quasar to get a better view of things falling into its black hole. NIRSpec and MIRI can also search for signs of planetary atmospheres: By monitoring stars with transiting exoplanets, they can watch for changes in their spectrum as the exoplanet's atmosphere absorbs certain wavelengths of the star's light.

All of the JWST's detectors are designed to be more resilient than Hubble's. When Hubble's detectors read out an image, they must transfer each pixel's accumulated charge down to the amplifiers at the bottom of the sensor to be read, line by line. But the sensor's ability to process charge degrades over time. On the JWST, the detectors avoid this by reading out every pixel individually.

Bringing Webb online

If all goes to schedule, around 7 A.M. EST one morning in late November, the Ariane 5 launch vehicle will lift off from Kourou in French Guiana, located near the equator in South America, setting Webb on a trajectory for L2. Soon after



ABOVE: A series of storms pirouette around Jupiter's north pole, imaged in infrared light by NASA's Juno spacecraft. The Webb will target Jupiter, its faint rings, and moons Ganymede and Io as part of its initial set of observing programs. NASA/JPL-CALTECH/SWRI/ASI/INAF/JIRAM

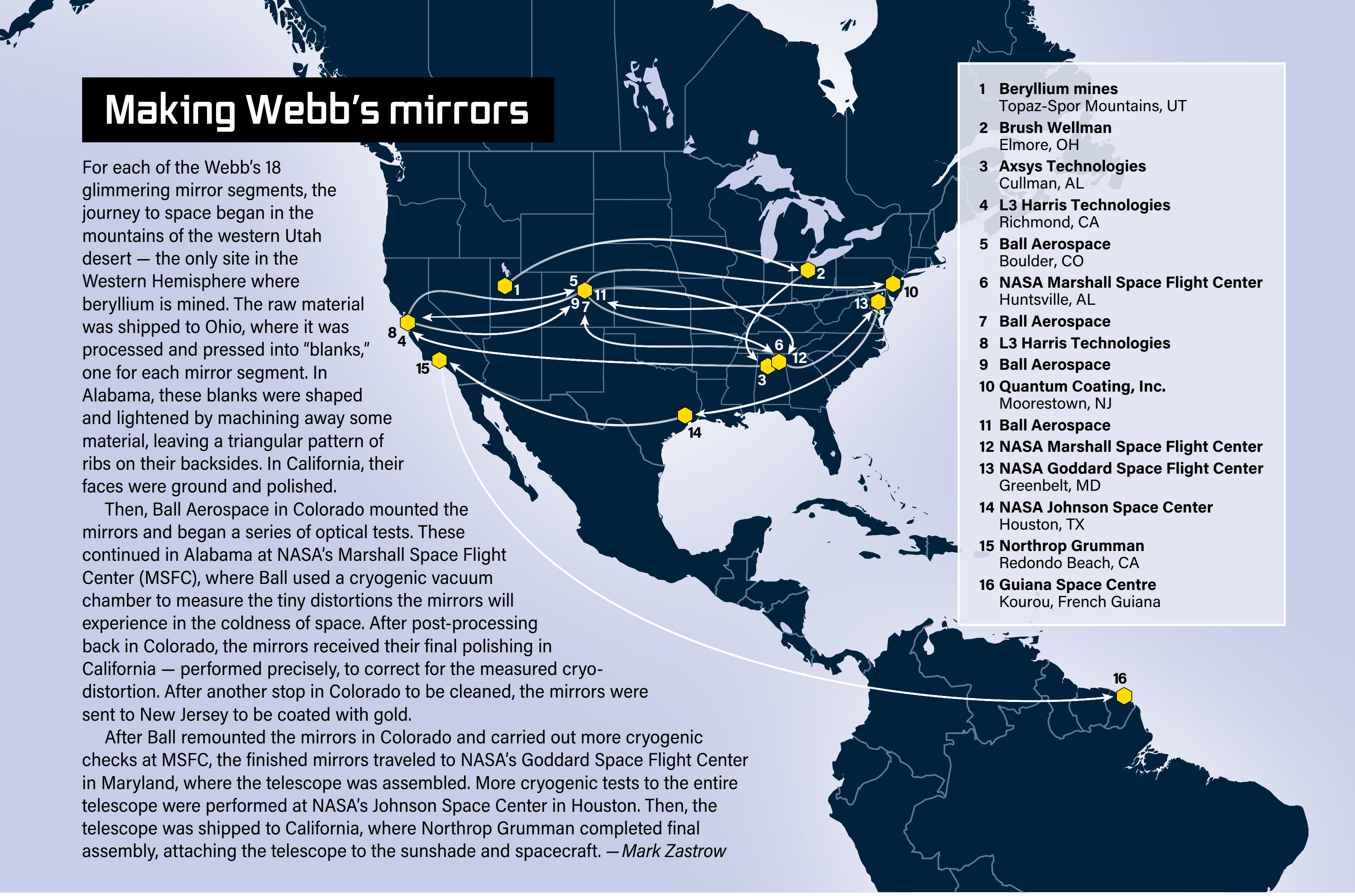
LEFT: Abell 2744 — also known as Pandora's Cluster — is a massive group of four galaxy clusters that act as a gravitational lens, bending light rays from background objects and magnifying them. Some of these lensed objects are visible in this image, appearing as arcs or rings. The JWST will use this to its advantage and study distant objects that date to the early universe. NASA

Making Webb's mirrors

For each of the Webb's 18 glimmering mirror segments, the journey to space began in the mountains of the western Utah desert — the only site in the Western Hemisphere where beryllium is mined. The raw material was shipped to Ohio, where it was processed and pressed into "blanks," one for each mirror segment. In Alabama, these blanks were shaped and lightened by machining away some material, leaving a triangular pattern of ribs on their backsides. In California, their faces were ground and polished.

Then, Ball Aerospace in Colorado mounted the mirrors and began a series of optical tests. These continued in Alabama at NASA's Marshall Space Flight Center (MSFC), where Ball used a cryogenic vacuum chamber to measure the tiny distortions the mirrors will experience in the coldness of space. After post-processing back in Colorado, the mirrors received their final polishing in California — performed precisely, to correct for the measured cryo-distortion. After another stop in Colorado to be cleaned, the mirrors were sent to New Jersey to be coated with gold.

After Ball remounted the mirrors in Colorado and carried out more cryogenic checks at MSFC, the finished mirrors traveled to NASA's Goddard Space Flight Center in Maryland, where the telescope was assembled. More cryogenic tests to the entire telescope were performed at NASA's Johnson Space Center in Houston. Then, the telescope was shipped to California, where Northrop Grumman completed final assembly, attaching the telescope to the sunshade and spacecraft. —*Mark Zastrow*



ALL ILLUSTRATIONS: *ASTRONOMY:* ROEN KELLY

The Webb's sunshield consists of five layers, each made of a high-performance plastic film called Kapton and coated with aluminum and doped silicon. NORTHRUP GRUMMAN

launch and while en route to L2, the telescope will unfold its antenna and solar arrays and start communicating with us in the control center in Baltimore.

Over the next few weeks, we will send commands to unfold the sunshade and the telescope's mirror, pausing to carefully check that each one is carried out correctly. (This is a luxury — when Mars landers tear through the Red Planet's atmosphere, they don't have time to phone home for help.)

Ensuring the observatory will unfold properly has required an extremely thorough test program, since we currently have no ability to visit L2 for repairs. To that end, the observatory is designed with electronic redundancy wherever possible — there are two ways to turn on every motor or to set off the release mechanisms that hold everything in place for launch.

After unfolding the telescope, we must focus it by precisely positioning each of the 18 hexagonal mirrors so they can work as one. The focusing algorithm was originally developed by Hubble scientists and engineers to correct that telescope's optics when it was launched out of focus; from lemons we made lemonade.

After all 18 hexagonal primary mirror segments and the secondary mirror are properly aligned, the telescope will be diffraction-limited at wavelengths of 2 microns and longer, meaning images at those wavelengths will be the sharpest that classical physics allows. If we are fortunate, the performance might be that good across an even wider range of wavelengths, but we won't know until we reach orbit and focus the telescope.

One month after launch, Webb will be close enough to L2 to begin orbiting around it, avoiding Earth's shadow so that solar power is always available. A week later, the telescope will have cooled enough to start focusing it. Three months after launch, all the instruments will be cold, and a month after that, focusing will be complete. Commissioning the instruments will take two more months, after which the scientific observing program will commence.

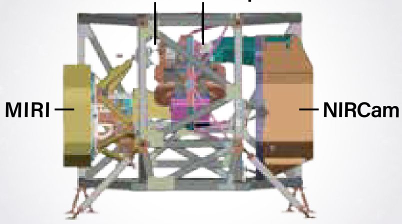
Where we'll look

The first scientific results will come from the Early Release Science program, based on 13 proposals chosen from over 100 teams that include over 4,000 astronomers from around the world. (All astronomers everywhere were eligible to submit their ideas.)

We also have an observing program designed by the teams who built the instruments, interdisciplinary scientists chosen by NASA, and 286 teams from

HOW JWST WORKS

Integrated Science Instrument Module (ISIM)

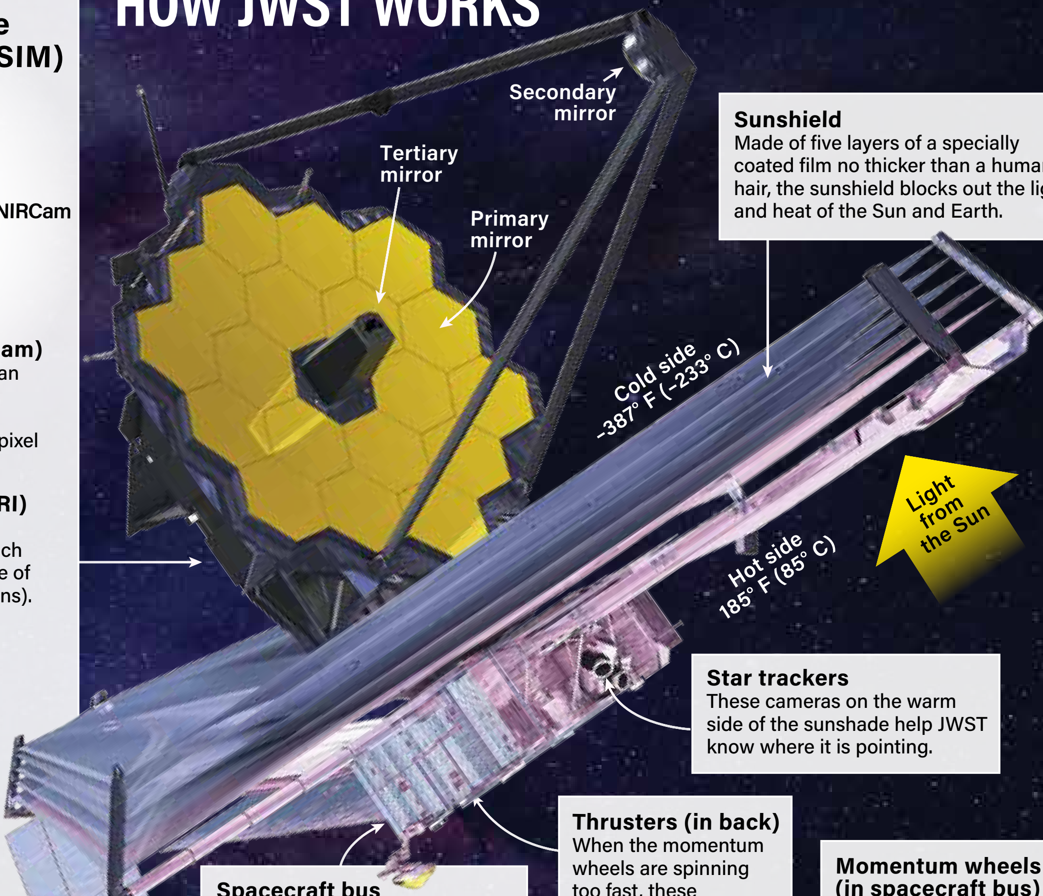


Near-Infrared Camera (NIRCam)
NIRCam pulls double duty as both an imager and the primary sensor for focusing the telescope. It's JWST's highest-resolution detector, with a pixel size of 0.032".

Mid-Infrared Instrument (MIRI)
MIRI is the only JWST instrument equipped with an active cooler, which allows it to operate at a temperature of just –447° F (–266° C or just 7 kelvins).

Fine Guidance Sensor/Near InfraRed Imager and Slitless Spectrograph (FGS/NIRISS)
To enable JWST to capture sharp images, FGS locks the telescope's line of sight onto a reference star in the field of view. The camera can track stars as faint as magnitude 18 and hold the telescope's aim to within a few milliarcseconds.

Near-Infrared Spectrograph (NIRSpec)
This unique spectrometer uses a microshutter array that can take spectra of 100 galaxies at a time.



Sunshield
Made of five layers of a specially coated film no thicker than a human hair, the sunshield blocks out the light and heat of the Sun and Earth.

Star trackers
These cameras on the warm side of the sunshade help JWST know where it is pointing.

Spacecraft bus
The bus (main body) contains supporting equipment and electronics. It's placed on the warm side of the sunshield so its heat doesn't affect observations.

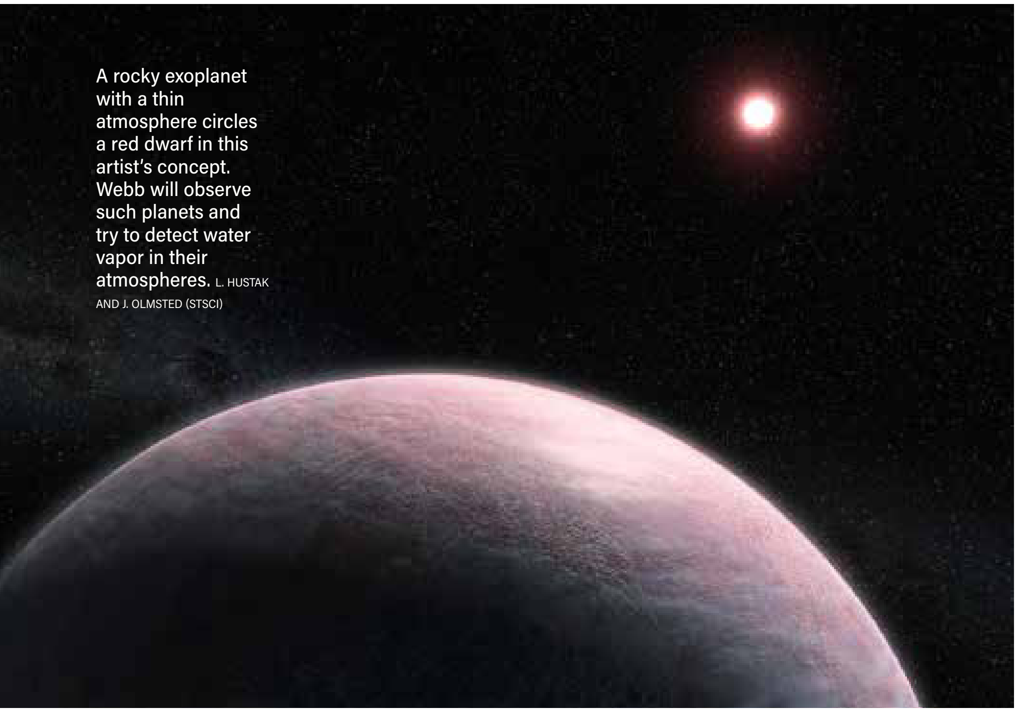
Thrusters (in back)
When the momentum wheels are spinning too fast, these hydrazine rocket jets are occasionally fired to help shed the wheels' accumulated angular momentum.

Momentum wheels (in spacecraft bus)
JWST orients itself with these flywheel-like devices, which spin up to generate torque and cause the craft to rotate.

LEFT: The JWST is lifted in folded configuration onto a stand in the clean room at Goddard Space Flight Center April 20, 2017. The primary mirror's "wings" are tucked back and the secondary mirror is also stowed, mounted to the two support struts straddling the center of the primary. NASA/CHRIS GUNN

ABOVE: The Webb's mirror was unfolded and deployed for its final pre-launch check April 21, 2021, at Northrop Grumman's facility in Redondo Beach, California. NASA/CHRIS GUNN

The Webb telescope and its sunshade were fully folded up in their launch configuration for vibration testing at Northrop Grumman in this photo taken Aug. 20, 2020. NORTHROP GRUMMAN



A rocky exoplanet with a thin atmosphere circles a red dwarf in this artist's concept. Webb will observe such planets and try to detect water vapor in their atmospheres. L. HUSTAK AND J. OLMSTED (STSCI)

At the heart of spiral galaxy NGC 4151 is a black hole with the mass of tens of millions of Suns, gorging itself on surrounding material. In its initial observing campaign, the Webb will measure the black hole's mass by watching how stars in the galaxy's central region move. NASA, ESA, AND J. DEPASQUALE (STSCI)

Are we alone?

In 1950, over a lunch with colleagues at Los Alamos National Laboratory, the Italian-American physicist Enrico Fermi famously asked, "But where is everybody?" He was referring to what we now call the Fermi paradox: If extraterrestrial civilizations exist, why haven't we seen them?

Here, I hazard my own guess: I think Earth is truly special, but the conditions for life are common elsewhere in the universe.

The evidence is simple but sparse. Geologists have fossil records showing that Earth was alive within a few hundred million years after it had oceans. But it took billions more years for the oxygen level in the atmosphere to begin to rise, and billions more yet for complex life with eyes and legs to turn up. And our own kind has been here for only a few hundred thousand years, a mere jot in the timescape. Altogether, our complex civilization took 4.6 billion years after the formation of the solar system to appear.

My answer to Fermi's question is that life is common — but complex life is rare, and life as complex as people is extremely rare. Furthermore, the distance between stars is immense. Even if we were to build a very patient, intelligent robot, it would have to travel for thousands to hundreds of thousands of years to reach another stellar system. If I were such an intelligent robot, I would prefer to stay home with my robot and human friends (and enemies). —*J.M.*

the research community chosen from 1,172 proposals. About 70 percent of the Webb's observing time will be for spectroscopy. (If a picture is worth a thousand words, a spectrum is worth a thousand pictures.) In addition, 20 teams were chosen for archival research and theoretical work.

Altogether, this initial series of observations will cover a vast range of astronomical targets and subjects.

We'll look at the solar system, including Mars, Jupiter, Saturn, Uranus, Neptune, Pluto, Eris, Sedna, Enceladus, Titan (where NASA is sending a helicopter), and Europa (where NASA is sending a probe to look for organic molecules in the moon's warm water geysers).

We'll look to Proxima Centauri — itself about the size of Jupiter — with at least one planet of its own, as well as Alpha Centauri, which also might have planets. We'll look at transiting worlds around red dwarf stars like TRAPPIST-1, and hunt for signs of planetary atmospheres.

We'll look into the famous Deep Fields pioneered by HST to peer further back in time and see — we hope — signs of the first galaxies being born.

We'll look through nature's telescopes: gravitational lenses, which are clusters of galaxies whose gravitational pull magnifies the images of even more distant galaxies behind them. Some of these lenses magnify their backgrounds by a factor of 10,000, which gives us a chance to see individual stars in the early universe.

Closer to home, we'll look at the Trapezium, the star cluster that makes up the middle "star" in Orion's sword. Where Galileo saw three stars by pressing his eye to his tiny telescope, our infrared camera will reveal a thousand newborn stars. And really close to home, when another interstellar interloper like 'Oumuamua comes by, we'll be ready to see if it's really a solid nitrogen pancake.

But what might we find that is completely unexpected? Dark matter, dark energy, and the black holes at the centers of most galaxies stand out as truly special, and have won their discoverers a rash of Nobel Prizes in the last decade.

I'm guessing that perhaps there were some kinds of objects formed in the early universe that have all disappeared, so we can't find them now. Maybe there were immense stars, thousands or millions of times the mass of the Sun, but burning out and turning into black holes and flying debris. Maybe dark matter was turning directly into black holes. Or maybe these strange objects are still here, but masquerading as something else.

Or perhaps there's something about exoplanets. Today, we know of thousands of them. We know that planets about the size and temperature of Earth are common, and maybe 20 percent of all stars

Onlookers gather around a full-scale model of the JWST at the South by Southwest conference, perched in front of the skyline of Austin, Texas. NASA/CHRIS GUNN

have them. With the Webb, we will search these planets for evidence of water, which we suspect is a requirement for life. Searching for oxygen is harder and we probably won't see it, but it would be a strong sign of photosynthesis.

What's next?

Just as Webb was conceived before Hubble even left Earth's surface, astronomers and engineers are already planning for the next generation of telescopes in space and on the ground.

The European Space Agency's 1.2-meter Euclid telescope (with U.S.-built detectors) is scheduled to launch in 2022 and will survey much of the sky to hunt for evidence of dark matter and dark energy. NASA's larger Nancy Grace Roman Space Telescope, with a 2.4-meter mirror (the same size as Hubble's), is planned for launch around 2026 and will take in 100 times as much sky in one bite as Hubble.

On the ground, the 8.4-meter Vera C. Rubin Observatory and its 3-gigapixel camera will survey the whole observable sky from its location every three nights, finding millions of short-lived transient events on every sweep, like supernovae, near-Earth objects, and matter falling into black holes. (JWST is ready and able to serve as a follow-up telescope for these finds: If a new discovery needs immediate response, we can do it within two days or less.)

Even larger ground-based telescopes — the 24-meter Giant Magellan Telescope, the Thirty Meter Telescope, and the 39-meter Extremely Large Telescope — are under construction. They are perfect for spectroscopy, which requires more light than taking images, and will be capable of imaging exoplanets (though not quite as small as Earth) around nearby stars.

For the next generation of space telescopes, the astronomical community will consult the recommendations of the 2021 Decadal Survey prepared by a committee of the U.S. National Academy of Sciences. Four projects are already under study by NASA: the far-infrared Origins Space Telescope, cooled to –452 F (–269 C, or 4 kelvins); the Lynx X-ray telescope, with much better mirrors and detectors than any of its predecessors; and the Habitable Exoplanet Observatory and Large UV/Optical/IR Surveyor telescopes, operating at near-ultraviolet, visible and near-infrared wavelengths, and optimized for directly imaging exoplanets.

None will be easy to build, but all are possible. In my opinion, each project is worthy of astronomers' time and effort. Together they could keep us fully occupied for at least half a century. Future generations will celebrate their accomplishments. More treasures await!

John Mather *is the senior project scientist for the James Webb Space Telescope. He led the Cosmic Background Explorer team that measured the spectrum of the Big Bang radiation and discovered its hot and cold spots, earning a Nobel Prize in 2006. His first computer was a circular slide rule and his first telescope had lenses from Edmund Scientific.*

Observe JWST yourself

Serious astrophotographers will be able to image the JWST in its orbit around L2, although it will appear only as a tiny speck. Its brightness will be quite variable as its orientation tilts relative to Earth and the oncoming sunlight, but typically will be around 16th to 18th magnitude.

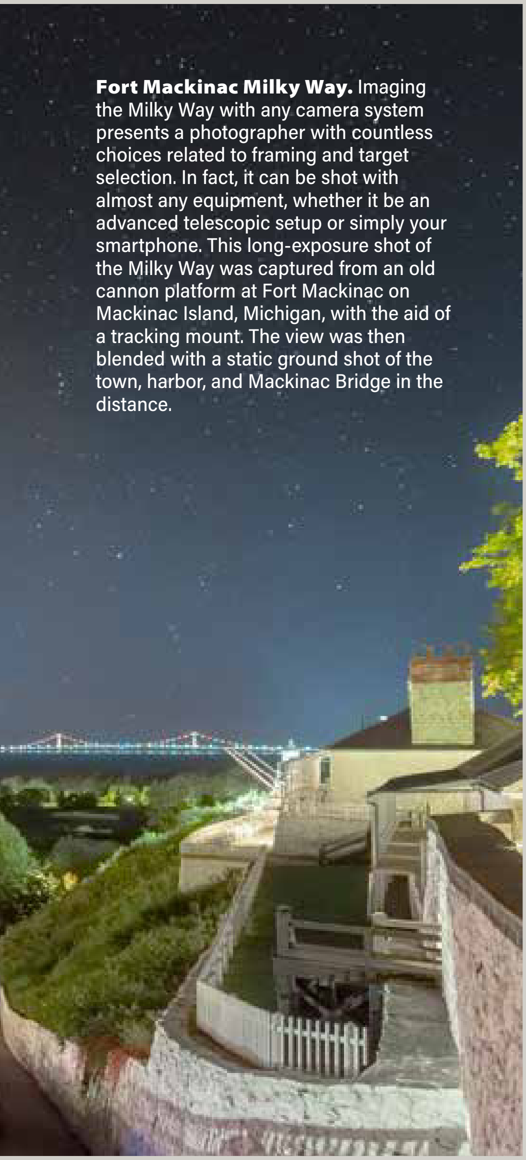
When the Webb is tilted just right, the flat solar panels or the stretched sunshield will reflect the Sun directly toward Earth, and its brightness will dramatically increase, possibly to 5th magnitude. Perhaps the thruster firings will be visible as well.

The JWST will move about 1" every 24 seconds relative to the background stars as it goes around the sky once a year. Amateurs could compute the craft's orbit from a series of images, starting with determining the parallax — and therefore, its distance — as Earth rotates. —*J.M.*

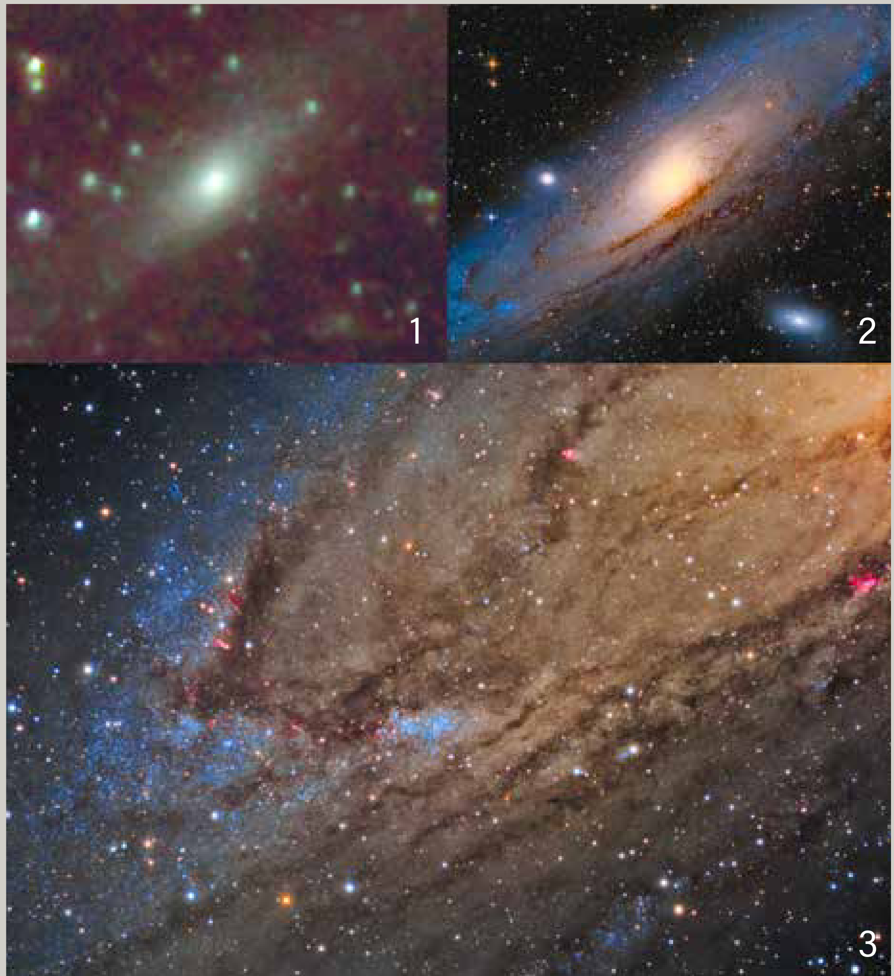
CAPTURING *the* COSMOS

Astrophotography takes loads of practice and plenty of patience. But the results can be truly spectacular.

TEXT AND IMAGES BY JASON GUENZEL



Fort Mackinac Milky Way. Imaging the Milky Way with any camera system presents a photographer with countless choices related to framing and target selection. In fact, it can be shot with almost any equipment, whether it be an advanced telescopic setup or simply your smartphone. This long-exposure shot of the Milky Way was captured from an old cannon platform at Fort Mackinac on Mackinac Island, Michigan, with the aid of a tracking mount. The view was then blended with a static ground shot of the town, harbor, and Mackinac Bridge in the distance.



1. First Galaxy Photograph: Andromeda Galaxy imaged with Canon Rebel T1i, Canon 50mm f/1.8 lens, fixed tripod (11 two-second exposures).

2. A Beginner's Setup: Andromeda with Canon Rebel T1i, 6-inch f/4 Newtonian, Celestron AVX (1.5 hours total exposure).

3. A More Advanced Setup: ZWO ASI1600MM, Celestron 8-inch EdgeHD, Orion Atlas Pro, LRGB filters (10 hours total exposure [378m; 75m; 75m; 75m]).

MOST NOVICE ASTROPHOTOGRAPHERS have a defining moment, when they find themselves staring in disbelief at what they just recorded in their camera. For me, that moment came a decade ago, standing outside on my back patio with a new Canon Rebel T1i DSLR. Although dark skies will reveal the Andromeda Galaxy to the unaided eye, suburban light pollution had forced me to clumsily determine its location using star charts. Targeting our galactic neighbor as well as I could, I simply took a string of exposures with a basic camera lens.

The setup was crude, at best. And the results were even more unsophisticated (see the image above). Still, that singular view on the back of my camera proved to me that astrophotography was something I could do from my own backyard.

I have never stopped striving for better results. Every year that goes by brings improvements in skill, hardware, and software that further enable amateurs. This is a golden age of astrophotography, and exploration of the vast cosmos is a journey that is accessible to anyone inspired enough to dive in — as long as they stick with it.

Getting started

With a background in aerospace engineering and product development, I'm no stranger to technical challenges, and that approach to problem-solving has been a significant asset on my journey. So, after seeing Andromeda 10 years ago through my DSLR, I immediately sought ways to improve. Progress came slowly at first. Fresh to the realm of astrophotography, I really knew nothing of the path on which I had embarked. I had little experience with photography of any sort, not to mention limited time and money. But over the nights, I realized I could do astrophotography my way, not worrying about getting it perfect from the get-go.

In 2013, I finally acquired a suitable telescope rig: an 8-inch Celestron EdgeHD and AVX mount. I had planned to spend most of my time with the scope visually observing the cosmos. But after my first few sessions, I never installed an eyepiece again. Instead, my Canon T1i took up residence at the back of the rig. Any experienced astrophotographer will

Galaxies

Galactic imaging offers a view out into the vast cosmos. In many cases, we can look back millions or billions of years using only an affordable backyard telescope. With countless options to choose from, exploring the menagerie of galaxies' varied shapes and structures never gets old.

1. The Phantom Galaxy. Peering more than 30 million light-years into deep space, past the Milky Way in the constellation Pisces, we come across a prime example of what's known as a "grand design spiral." M74 is an orderly and very structured face-on spiral galaxy. Among the faintest objects in Messier's famous catalog, it has picked up the "Phantom Galaxy" moniker due to its fleeting nature in visual observations.

2. The Needle Galaxy. About 40 million light-years away, looking toward the constellation Coma Berenices, lies a beauty of an edge-on spiral: NGC 4565. It is truly one of the finest examples of its kind that is visible from Earth.

3. A polar ring galaxy. Looking far out into the constellation Pisces, we come across this petite cosmic gem. NGC 660 is estimated to be 45 million light-years away and spans only a few arcminutes, which makes it quite small. This galaxy is unique due to the oblique angle — about 45 degrees — of its polar ring.

4. The Sunflower Galaxy. M63 has an incoherent, fluffy appearance and is known as a flocculent spiral. Though more recent studies in infrared have revealed the galaxy's spiral arms, they are not optically apparent. The extended halo (just barely visible here to the upper left of the core) indicates a past galactic interaction, as evidenced by the warped, offset loop. At just 30 million light-years away, M63 appears as one of the larger galaxies in the night sky, providing even those with amateur scopes detailed views.

tell you this setup was not ideal for a novice, but we tend to be a stubborn bunch, so I pressed on.

I quickly learned which components were impeding my results, and by 2016, I had improved the system to the point where it was providing reliable, quality images night after night. This is still my primary imaging telescope, although everything attached to it has been upgraded in some way. The upgrades took time, and few by themselves were game changers. Adding an autoguider allowed me to take longer exposures and installing an autofocuser improved my ability to repeatably focus the telescope. Another key improvement came with my purchase of a cooled monochrome astronomy camera. The image quality of this device far surpassed that of my previous DSLR, allowing better results with far fewer post-production headaches.

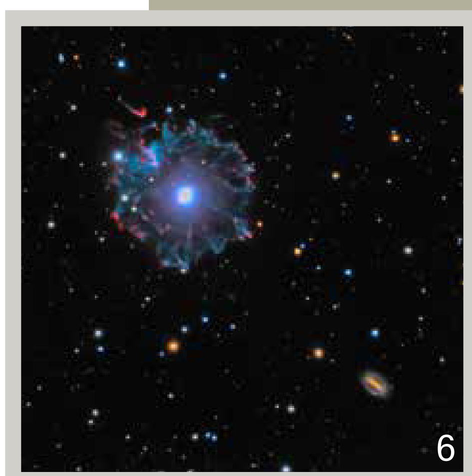
Lastly, I focused on automating my setup with software. Although many options exist now, Sequence Generator Pro was one of the first affordable choices on the market, and it is still my go-to because of its ease of use and familiarity. It allows for planning, sequencing, and full nights of automated imaging — no micro-management or intervention required. With this program, I found myself setting up more often and letting it run while I went about other business, which was often processing the results from earlier sessions. Once automation was a reality, I was able to let the telescope collect a night's worth of images even while I slept.

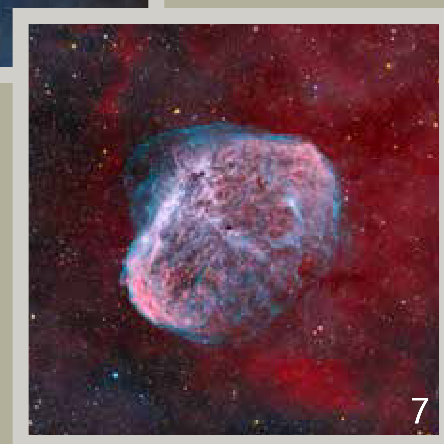
Selecting your hardware

The configuration I settled on for most of my deep-sky photography is that Celestron EdgeHD 8-inch telescope with the 0.7x reducer, Moonlite CHL focuser, Orion Thin Off-Axis Guider, ZWO ASI120MM guide camera, ZWO Electronic Filter Wheel with Astronomik

Nebulae

These beautiful clouds of interstellar gas are the hallmarks of stellar formation and death. By using narrowband filters, we can cut through the haze of artificial light pollution, revealing emission and planetary nebulae in great detail. If conditions are good, the dust in the Milky Way can also be captured in photographs as dark and reflection nebulae.





5. Inner Soul. The Soul Nebula (IC 1848) is a nearby star-forming region in the constellation Cassiopeia. Its young, hot stars carve out and ionize pockets of nearby gas, causing them to glow in sculptured forms. This high-magnification view showcases the very center of the extended nebula. A cropped version of this image, which required 38 total hours of exposure time, was selected as NASA's Astronomy Photo of the Day in November 2020.

6. The Cat's Eye. A millennium ago, the central star of NGC 6543 began its transition from a red giant to a hydrogen-depleted state. It shed its outer atmosphere into space, leaving behind a bare oxygen and carbon core. This expanding planetary nebula, photographed in both narrowband and LRGB over some 26 hours, is continually shaped by violent yet surprisingly subtle forces.

7. The Crescent. This wild nebula, NGC 6888 in Cygnus, is a result of competing stellar winds shed from the Wolf-Rayet star within. Late in its life, the star is actively fusing heavy elements. This violent production of energy has blown out most of the hydrogen and helium from the star's outer atmosphere, giving rise to the delicate and fascinating structure of the surrounding emission nebula, which was captured here thanks to nearly 27 hours of exposure time.

LRGB and narrowband filters, and ZWO ASI1600MM main imaging camera. All of this rides on an Orion Atlas Pro telescope mount. Ancillary gear is also required, in the form of power delivery and distribution, dew mitigation, USB hubs and cables, and, of course, computer control. There are no turnkey solutions here, and it is up to the user to construct and optimize their individual system.

This setup operates at a focal length of just under 1500mm and offers an excellent balance of system performance and value. It was perhaps a backward approach, as most novice astroimagers begin exploring the capabilities of scopes with widefield images. But I started by shooting galaxies and nebulae at long focal lengths. I was fascinated by the tiny details of distant objects. This type of photography was a tremendous challenge, especially for a beginner. It required extreme precision and any errors were magnified. I worked hard to continually optimize the system's performance, and I could eventually produce results that were limited only by my sky conditions.

Although I initially focused heavily on this imaging rig, I also developed a keen interest in even more basic and accessible gear. This led me to working on and testing many other imaging systems. Of these, a good number have proven to be quite versatile, offering excellent value. I have amassed a collection of hardware: telescopes, lenses, cameras, filters, mounts, and so on. And by using them, I have come to understand the benefits and drawbacks of each.

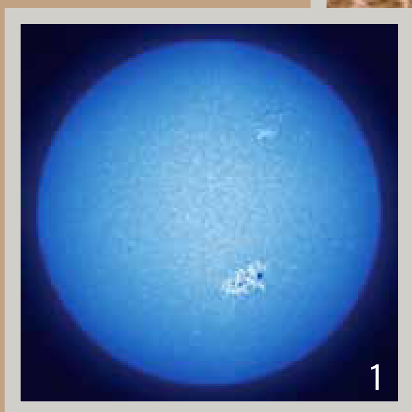
Acquiring your target

As an astrophotographer without a permanent observatory, I've had to work hard to expedite setting up my equipment for each night of imaging. I have made this task easier by leaving most of my gear assembled between sessions, letting me move it as one piece. Once outside, I simply complete the necessary polar alignment. I can usually be imaging the sky in mere minutes.

As I mentioned earlier, I constructed my system with the goal of automating as much of the imaging process as possible. On a typical evening, I will select my targets and schedule the session. Then, once I click "start," the system points the telescope, focuses, engages autoguiding, and

The Sun

Solar photography can be incredibly rewarding — and you don't have to stay up all night to do it. (Although you do need a filter.) Consumer-grade equipment costs have dramatically come down, and chromospheric structures that were once limited to the realm of professional-grade observatories are now within the reach of backyard solar telescopes.



1. Solar calcium. Just past the extreme blue end of the visual spectrum and into the ultraviolet lies the Calcium H emission line. Sunlight filtered to this narrow band of light reveals a unique look at the upper atmosphere of our star.

2. Active Region 2804. The Sun reveals features of the plasma in its chromosphere in this stacked and contrast-enhanced view taken with a Hydrogen-alpha (Hα) filter Feb. 27, 2021. Active Region 2804 — a bright, oblong sunspot that could swallow Earth whole — sits near the upper edge, showing off its tangled magnetic field.

3. Sunspot in AR 2786. This extreme close-up shows the details of a magnificent sunspot that was visible on the Sun Nov. 28, 2020. Such spots are caused by local magnetic fields interacting with hydrogen plasma, which cools the area and makes it appear darker than its surroundings.

begins imaging. I will generally target a few objects per night using various filters, selecting the optimal times for capturing each based on current conditions. The software even employs a recovery mode for restarting the sequence when something goes wrong. This is not uncommon and can be triggered by many things, such as a cloud passing overhead.

Beating light pollution

Most of my astrophotography work is done from my moderately light-polluted suburban backyard patio. The site rates a Class 5 on the Bortle scale, which ranges from 1 (no light pollution) to 9 (extreme light pollution). Though some types of astrophotography — like imaging the planets, the Sun, and the Moon — are relatively unaffected by artificial skyglow, the intrusion of light pollution in deep-sky images greatly increases noise and diminishes photographic contrast. But don't fret, there are ways to combat it.

My primary strategy is to focus on getting longer total exposure times. This effectively reduces background noise in a stacked image through the process of averaging, which improves the signal-to-noise ratio. For particularly faint objects, this means I might require 50-plus hours of exposure comprising several hundred sub-frames, which must be built up over many nights of imaging.

Another method to combat light pollution is using narrowband filters. These filters completely reject extraneous light, allowing only the light from ionized gases in space to pass through. Furthermore, narrowband filters also block unwanted moonlight, allowing you to capture deep-sky images at any time during the month.

It is still true that the best results come from beneath extremely dark skies, but the gap is closing. For me, constantly venturing to a worthy dark-sky site or using a remotely hosted telescope system isn't a realistic possibility. But working from home, even with modest equipment in suboptimal conditions, I'm able to use the aforementioned techniques to produce astonishing results that simply were not possible a few decades ago.

Software processing

Physically capturing shots of cosmic objects with specialized equipment is only a small part of the final product. Post-processing my results, in most cases, is the most significant factor in how an image turns out. My journey in front of the computer screen has been significantly longer and more complex than managing the gear outdoors.

For deep-sky imaging, I started processing my images using Deep Sky Stacker and software I already used for my daytime photography work: Lightroom and Photoshop. Digging in a bit deeper, I transitioned to the more astrophotography-focused PixInsight for my entire preprocessing workflow, including deconvolution, noise reduction, and histogram stretching. I still use Photoshop for final color editing and enhancing details. I've also added plug-ins from TopazLabs to help in this regard.

Post-processing different types of astroimages calls for different techniques and software. For example, solar system imaging employs many different pieces of software, but much of it is available for free or for a donation. Examples include Firecapture, SharpCap, Autostakkert!, PIPP, ImPPG, and many more.

The Planets

The solar system's planets appear extraordinarily tiny in the sky. And although instruments with a long focal length and a large aperture certainly help reveal worthy details, they aren't strictly required for astrophotography. To combat the effects of atmospheric turbulence, you can shoot many thousands of images before grading and stacking them. Learning to apply sharpening algorithms can also help you make your results appear crisper.

The favorites. Mars, Saturn, and Jupiter during the 2020 season (July to October), as viewed through a 12-inch imaging Newtonian. Each planet was captured in detail as it approached its opposition point nearest Earth.

Special events

Whether it's comets, eclipses, planetary conjunctions, aurorae, meteor showers, satellite transits, or anything else astronomical, sometimes the greatest challenge in imaging sky events is finding out about them in the first place. Generally, a magazine, observing guide, online forecasting resource, and/or planetarium software can greatly help you stay informed on the most significant upcoming events. For location-specific treats, such as aurorae or a space station transiting the Sun or Moon, forecasting websites are indispensable resources.

Great American Eclipse. The awesome beauty of nature was on full display during totality of the solar eclipse Aug. 21, 2017. Totality is truly a sight to behold, and perhaps the finest example of a special astronomical event. Totality's brevity can also make it a very stressful time for a first-time eclipse photographer. But no matter what, you should try to take at least a few moments to observe the sight with only your own eyes.

The Moon

Imaging Luna is perhaps the easiest and most natural point of entry for most aspiring astrophotographers. Basic shots, including those taken during lunar eclipses, are not very difficult to capture. And over time, you can learn how to enhance highlights and color variations produced by compositional differences in lunar regolith.

Moon hues. By increasing the saturation of the Moon's natural colors and boosting the contrast between features, the lunar surface can come alive with a new perspective. The multi-colored surface seen here is a result of different soils and layers that were created and spread through both chemical and mechanical processes. Some examples of this include the bright rays deposited by impact ejecta, the vast plains created by ancient lava flows, and the darkening effects of space weathering.

Software editing allows me to add a personal, artistic touch to my images. And it can transform a rather mundane shot into an eye-catching photograph. Honing these skills is instrumental to improving the final quality of my results, and it has been vital to achieving my goals as an astrophotographer.

The continuing inspiration

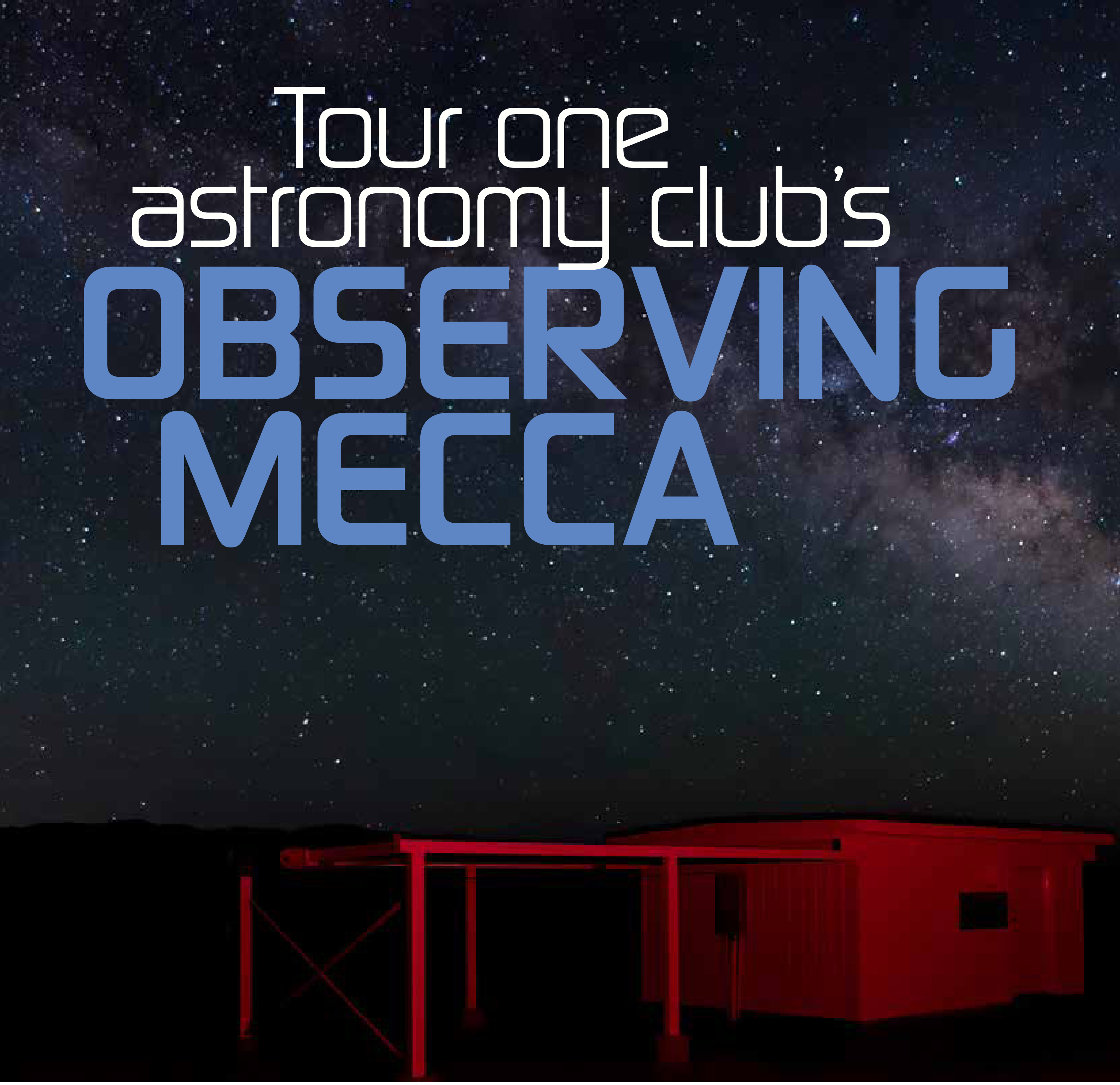
The further I became immersed in astrophotography, the more abundantly clear it became that there are many more possible avenues to explore. Space is vast and hides countless varied gems just waiting to be captured. I began with deep-sky photography of distant galaxies and nebulae, but in time I branched out and bagged shots of the Sun, the Moon, bright planets, our Milky Way, and even some unique astronomical events like comets, eclipses, satellite transits, aurorae, and more.

Astrophotography has grown to become a defining aspect of my life. Over the years, my work has been published, awarded, and shared widely. It has been truly exciting to see my photos in print, selected as NASA's Astronomy Photo of the Day, and even put on display in a museum for having won an award in the Astronomy Photographer of the Year competition in Greenwich, England.

Imaging the sky has always been a deeply personal hobby that allows me to tour the universe. The images shared in this article are postcards from that journey. I find inspiration in capturing the vast cosmos, as well as reflecting on our tiny place within it. I hope you will too.

Jason Guenzel*'s catalog of work can be found on major social media platforms: @thevastreaches*

Tour one astronomy club's OBSERVING MECCA



The Tucson Amateur Astronomy Association is preserving and sharing dark skies at its observing complex near the Chiricahua Mountains. BY JIM KNOLL

SEEING A BRIGHT MILKY WAY flowing across the sky is an experience like no other. And observing many beautiful naked-eye deep-sky objects significantly enhances any astronomical session.

Unfortunately, many astronomy clubs have to deal with ever-increasing light pollution in the cities where they live and observe, forcing them to explore alternate locations for observing. We at the Tucson Amateur Astronomy Association (TAAA) are no exception. Over the past 10 years, our club — which comprises almost 500 members — has been busy building a premiere dark-sky site called

Sitting beneath the arc of the Milky Way is the Wallace Rogers Observatory, part of the Tucson Amateur Astronomy Association's Chiricahua Astronomy Complex. This 10-second single-exposure image was captured with a Nikon D750 full-frame camera and Nikon 20/1.8G lens. KEVIN COOK

The Reynolds-Mitchell Observatory's 40-Inch Starstructure Dobsonian telescope, nicknamed Big Boy, provides amazing views of the dark desert skies. Here, Chief Telescope Operator Carter Smith stands at the eyepiece, while John Kalas operates the controls. SUSAN KNOLL

the Chiricahua Astronomy Complex (CAC). This 16-acre (6.5 hectares) facility lies in the Arizona desert, about 15 miles (24 kilometers) from the Chiricahua National Monument, situated in the plateau between the Chiricahua Mountains to the east and the Dragoon Mountains to the west.

With Tucson — the nearest major city — 100 miles (160 km) to the northwest, our dark site sports a Bortle 1 sky. (The Bortle dark-sky scale measures the amount of light pollution affecting the sky in a given location. A rating of 1 is the best possible sky, where M33 is visible to the naked eye.) And the dry desert air at 4,800 feet (1,460 meters) elevation makes for some incredible observing.

A closer look at CAC

CAC is funded primarily by donations from individual TAAA members and local Arizona private nonprofit foundations. "TAAA has extremely generous members," says club president Mae Smith. "Throughout the years, members have given generously to fund the development of CAC and donate the exquisite telescopes and amenities that provide a first-class observing experience. It would have been extremely difficult to accomplish this effort without the assistance of all our members and local foundations."

In fact, TAAA members were instrumental in the purchase of the CAC site. Following an extensive search in southeastern Arizona, Smith says, in 2007 the club finally found the right spot, near the Chiricahua Mountains. Four members (the Perseus Group) then purchased 40 acres (16 ha) of land, donating the central 16 acres (6.5 ha) to TAAA in 2008, while each retained ownership of a protective 6-acre (2 ha) parcel around the central complex. Due to increasing light pollution in Tucson, we needed a dark-sky location for members to hone their observing skills while providing a place to socialize and enjoy our hobby. This site had dark skies yet was still close enough to Tucson for member access.

Once the property had been secured, TAAA formed a Strategic Planning Committee to design and develop a fantastic observing complex. John Kalas was an original committee member and served as the first CAC director. "It was important to ensure we had a well-designed complex that would allow seamless expansion while maintaining the dark skies with an observing experience second to none," he says.

Amenities at CAC currently include four RV sites with electricity, two restrooms, a shower, ample parking for members and visitors, and a ramada picnic area. And the club continues to incrementally expand CAC to better serve its members and community throughout southern Arizona, Kalas says.

The equipment and amenities at CAC provide the opportunity for members to take their observing and imaging to the next level. The Reynolds-Mitchell Observatory has a 40-inch Starstructure Dobsonian go-to telescope — a very large telescope for an astronomy club. It also houses a unique 9-inch folded refractor, made by Matthias Wirth of Germany, on an Astro-Physics mount situated on an observing deck. Views through the 40-inch scope are so vivid that it makes you feel like you are inside the object you are observing, while the 9-inch refractor is a nice complement to the larger Dob.

These two telescopes are adjacent to a large warm room with plenty of space for members to gather. The telescopes operate during our member observing sessions around New Moon and during TAAA's semiannual Evening Under the Stars event, when the site is open to neighbors and the general public. This event is a chance for the local community to see the facility and experience their night sky more fully than they do day to day. It also serves as an opportunity to show our neighbors what CAC is all about, talk about the outreach education mission, and discuss why dark skies are important.

The association also has a 14-inch Celestron Schmidt-Cassegrain Telescope (SCT) on an Astro-Physics 1200 mount in a roll-off roof observatory, available for member use. Members can also get trained to use a 25-inch Obsession telescope on a 27.6-foot (8.4 m) circular observing pad. Together with the 40-inch and 9-inch telescopes in the Reynolds-Mitchell Observatory, these four scopes provide excellent astronomical views for members in a variety of optical configurations. The Dobs, refractor, and SCT can also be configured with imaging or video cameras, allowing members to capture the night sky for personal and club outreach use.

To facilitate use of CAC under these incredibly dark skies, members can access any of 10 observing pads, each with power, to set up their own equipment. There are an additional 10 pads available for specific members' exclusive use under long-term leases. Future plans include expanding the number of pads available to members.

On average, 20 to 30 members use the site around New Moon each month. However, this changed in 2020, when our facility shut down during the peak of the COVID-19 pandemic. We initially reopened on a limited basis with restrictions in March 2021 to allow our members to begin using the site as a respite from the ongoing issues related to the pandemic. Escaping into the universe through one's

The Chiricahua Astronomy Complex boasts clear, dark skies from its location 100 miles (160 km) southeast of Tucson, Arizona, and 15 miles (24 km) southwest of the Chiricahua National Monument. *ASTRONOMY*: ROEN KELLY

THE GRAND CANYON STAR PARTY

TAAA co-hosts, along with the National Park Service, the Grand Canyon Star Party on the South Rim each June for eight nights around New Moon. This public outreach event averages 60 telescopes and about 1,700 visitors from all over the world each evening. In addition to our TAAA members, volunteers come from all over the U.S. The dark skies at 7,000 feet (2,130 m) along the South Rim are exceptional, with a vivid Milky Way arcing overhead.

This year, the event was held virtually for a second year in a row, organized by Ranger Rader Lane. It ran from June 5 to 12, streaming daily astronomy talks and the nightly star party to the Grand Canyon National Park's social media. Next year's Grand Canyon Star Party will hopefully be back to an in-person event. It will run from June 18 to 25, 2022. —*J.K.*

CAC has 10 observing pads available for members to set up personal equipment for observing and for use during astronomy outreach events. SUSAN KNOLL

telescope is a wonderful way to provide that much-needed diversion. We fully opened again in May and member use soared even higher.

Reaching out

One of TAAA's primary missions is to provide astronomy education and outreach throughout Tucson and parts of southern Arizona. TAAA puts on an average of more than 200 outreach events annually for school and youth groups, the public, and resort guests. These events are supported by more than 60 TAAA member volunteers. Because CAC is so remote, most outreach events are conducted on the grounds of the particular school or organization. This means sometimes having to deal with significant light pollution, but we still work to provide an eye-opening educational experience for the public.

During the COVID-19 pandemic, however, TAAA shut down all in-person outreach. Like many organizations, the club had to pivot and come up with other methods to share the wonders of universe. TAAA extended

its astronomy education to virtual activities streamed — often live — via its Facebook page and YouTube channel. The learning curve was steep, as none of the members had produced virtual events in the past. But this allowed us to bring our unique equipment, observing conditions, and expertise to others in a way we'd never accomplished before.

It was remarkable how quickly our core virtual volunteers — Bernie Stinger, Jim O'Connor, Rick Paul, and myself — mastered doing these star parties. Using video and astroimaging cameras along with a planetarium program, the team put on a show to explain astronomy in a way that everyone could understand and enjoy. These virtual events had the added benefit of extending our reach from southern Arizona to all of the U.S., and even the entire globe.

Our team has put on 18 virtual events so far. With each virtual star party came experience that improved the team's ability to share these wonderful sights Additionally, incorporating the use of the club's large telescopes at CAC has revealed a whole new set of objects to share, thanks to these instruments' ability to show fainter and less-observed targets. Because of the broad and far-reaching audience, TAAA plans to continue virtual events even after resuming in-person activities.

JOIN US!

» Annual membership in TAAA is modest and required to use CAC unless you are a guest of a member. For more information about TAAA, visit http://tucsonastronomy.org.

» For information about CAC and the projects listed here, visit http://tucsonastronomy.org/taaa-member-resources/observing-sites/chiricahua-astronomy-complex/ or select "TAAA Resources" and then "Observing Sites" from our homepage's main menu.

» You can join TAAA volunteers on the next Virtual Star Party, which will stream to the TAAA Facebook page at www.facebook.com/TucsonAstronomy, or on our YouTube channel — just search for "Tucson Amateur Astronomy Association" within YouTube.

More progress ahead

TAAA is particularly proud of the expansion currently underway at CAC to build a state-of-the-art astronomy learning center to facilitate even more astronomy education and outreach opportunities away from the city lights. According to club member Mike McDowell, who oversees the construction work for the club, "The center is comprised of two buildings with 10 sleeping rooms, classroom space, restrooms, and shower facilities for overnight youth groups and member use. It also includes four additional telescope pads that will house a 9¼- and 11-inch Celestron SCT, a 12-inch Meade SCT, and an 18-inch Obsession for hands-on use during educational outreach."

Some telescopes will be equipped with cameras for students to take images of their observations for school projects or their own studies. These telescopes can also be used to stream virtual events to TAAA social media or to off-site locations such as schools or other organizations.

Once complete, TAAA will invite school and youth groups back to CAC. And we are excited for the opportunities the new facilities and equipment will provide to our outreach mission. It will enhance the site's capacity to have discussions, planning, and activities inside a classroom, followed up by observing through the telescopes.

"TAAA's next expansion project [after the leaning center] is in the planning stage and will be starting this fall," says Bob Reynolds, CAC strategic planning director. "This stage of development includes building up to 17 member observatories, three observing pads with storage for large Dobsonian telescopes, access roads, parking spaces, and extending the site's high-speed fiber-optic connection to the observatories. These observatories will be for exclusive long-term member lease and will be roll-off roof style facilities."

For additional information or to become part of this project, visit our Member Observatories webpage at: http://tucsonastronomy.org/member-observatories/ or email memberobservatories@tucsonastronomy.org.

TAAA is excited and proud to have such an extensive dark-sky complex available for members to use and to share the wonders of the night sky with our local community, youth groups, and students throughout southern Arizona and the U.S. "Our Chiricahua Astronomy Complex should accommodate our growing needs well into the future," Smith says. "We cannot wait to see what new opportunities will come our way as we continue our astronomical adventures!"

Jim Knoll *is the Chiricahua Astronomy Complex director and the Tucson Amateur Astronomy Association star party manager.*

Visible to the naked eye
Visible with binoculars
Visible with a telescope

THE SOLAR SYSTEM'S CHANGING LANDSCAPE AS IT APPEARS IN EARTH'S SKY.

BY MARTIN RATCLIFFE AND ALISTER LING

Mercury takes center stage in this early January 2018 shot. The solar system's smallest planet once again rules the dawn twilight this month in its best morning appearance of 2021. ALAN DYER

Catch Mercury in the morning

Mercury springs into action in the last two weeks of October, offering its best morning appearance for 2021. Venus, by contrast, hangs low in the southwestern sky all month. Jupiter and Saturn dominate the evening sky, visible through midnight. And late-evening binocular views of Uranus and Neptune beckon more adventurous observers.

Let's begin in the evening sky. **Venus** is visible soon after sunset, low in the southwest. It begins the month at magnitude –4.2 and brightens to –4.5 by Oct. 25. The planet lies in Libra for the first week of October and crosses into Scorpius Oct. 7. Venus spends part of Oct. 15 crossing a small corner of Ophiuchus, before returning to Scorpius and passing 1.5° north of Antares on the 16th. It returns to Ophiuchus Oct. 21 and stays there through the end of the month.

Venus reaches its greatest elongation east of the Sun Oct. 29, when it stands 47° from our star. However, this does little to increase the planet's altitude after sunset, due to the low angle of the ecliptic to the western horizon. An hour after sunset, Venus is always between 7° and 11° high.

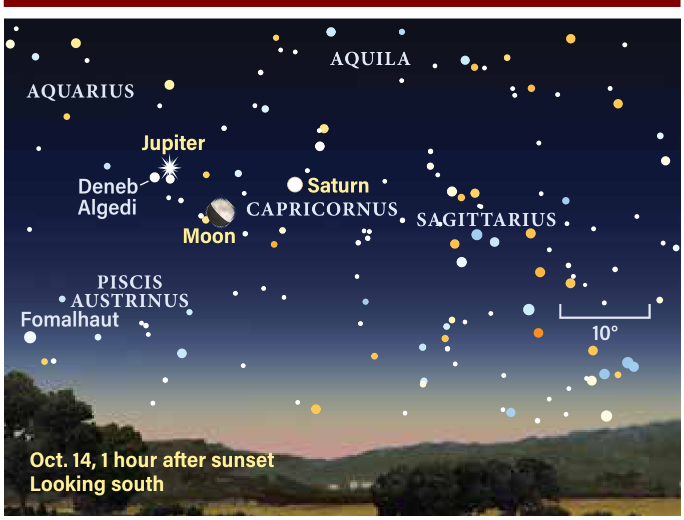
Any telescope reveals its changing appearance. On Oct. 1, the planet subtends 19" and is 62 percent lit. The disk grows to 24" by Oct. 27 and reveals a lovely half-illuminated phase. By Halloween, the disk spans 26" and is less than 50 percent lit.

One observational curiosity is the moment the phase reaches exactly 50 percent. Venus' observed phase often differs from the calculated phase. Called Schröter's effect, the onset of dichotomy might be observed up to a week before Oct. 27. The likely culprits at the heart of this effect are the dimness of the central part of the terminator combined with the scattering of light in the venusian atmosphere. When do you observe Venus as 50 percent lit?

As soon as the sky is dark, look low in the south for two bright objects. The westernmost is Saturn, followed by Jupiter 16° farther east. Both are in Capricornus the Sea Goat.

Saturn's motion against the background stars grinds to a

In the company of giants



A waxing Moon slips between Jupiter and Saturn midmonth. Zoom in on each planet with a telescope for additional detail. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

OBSERVING HIGHLIGHT

MERCURY reaches greatest western elongation Oct. 25, shining at magnitude –0.5 in the early-morning sky.

halt as its retrograde path ends Oct. 10 and it resumes eastward motion. The planet's movement is barely noticeable by eye. Saturn shines at magnitude 0.4 in early October and dims by 0.1 magnitude in the latter half of the month. On Oct. 13, Saturn stands about 6° northeast of a waxing gibbous Moon.

The giant is a stunning sight in a telescope, with the best viewing in the few hours after sunset. The magnificent ring system, tilted by 19° to our line of sight, is clearly on view around the 17"-wide planetary disk. The northern face of the ring system is now visible. Over the next few years, the rings will become narrower, revealing more of the planet's southern hemisphere. The brightest ring is Ring B, separated from the duskier Ring A by the Cassini division. Ring C, or the Crepe ring, is quite thin. You should be able to see the planet through it.

Saturn's yellowish disk reveals few details. Rare storms do pop up, so watch for small white spots that might develop into something larger. An equatorial belt is often visible under good seeing conditions.

The brightest moon of Saturn, magnitude 8.5 Titan, is easy to see through any telescope. It appears north of the planet Oct. 5 and 21, and south of the planet Oct. 13 and 29.

A trio of 10th-magnitude moons orbit closer than Titan. Tethys, Dione, and Rhea are quite easy to spot. More difficult is Enceladus, shining near magnitude 12. It lies close to the bright edge of the rings.

Iapetus reaches superior conjunction Oct. 10, then progresses east, reaching greatest elongation Oct. 29. Its darker face has turned earthward, dimming it to 12th magnitude.

— *Continued on page 38*

RISING MOON | Splish splash

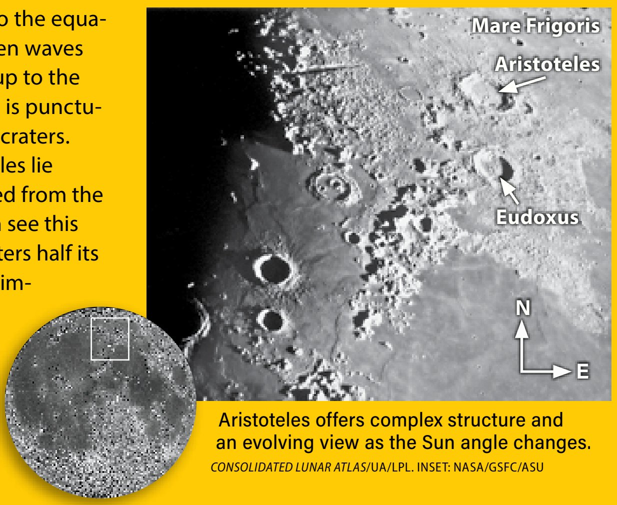
A DAY BEFORE FIRST QUARTER, the Moon shows us a face of thirds. The south is a crowded, cratered mess that quickly morphs into the equatorial slate gray seas, whose large frozen waves are known as wrinkle ridges. Venture up to the northern third, where the smoothness is punctuated by a handful of large identifiable craters.

On Oct. 11, the ramparts of Aristoteles lie aglow in the rising Sun, mostly emerged from the terminator. One Earth day later, we can see this marvelous, complex crater fully lit. Craters half its 50-mile size boast cleaner lines and a simpler peak, but Aristoteles' features suffered much more during the greater energy release of a larger impact. In moments of good seeing, there is a lot of structure to see here.

Splattering back down after the blast, the vast amount of excavated soil spreads a large apron around Aristoteles, creating an uncountable number of small secondary craters. You can only see them flit in and out of view in the slanted light near lunar sunrise or sunset. By the 13th, the higher lunar Sun has erased these shadowlets from view. The inner crater walls, weakened from the impact, have slumped into a series of terraces. Millions of years later, lava welled up from underneath, flooding the inside — but not quite enough to cover the peaks at the center.

Return for a look around Full Moon and pop in a filter to cut down on the glare. Sweeping in a gentle arc of dark gray across the lunar north is Mare Frigoris. Aristoteles has been transformed to an oval of light material, paired with the smaller, more circular crater Eudoxus just to the south. What a change solar noon brings!

Aristoteles



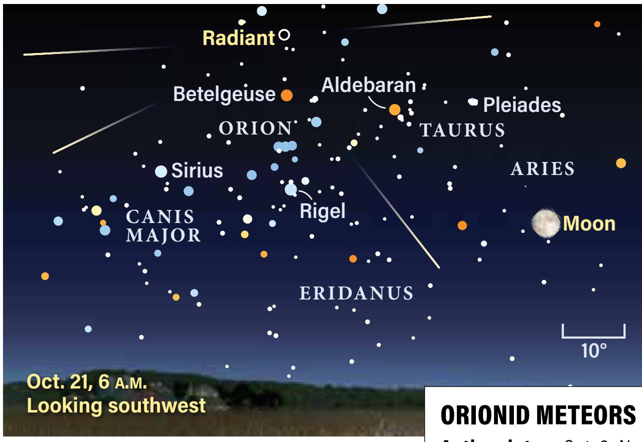
Aristoteles offers complex structure and an evolving view as the Sun angle changes.
CONSOLIDATED LUNAR ATLAS/UA/LPL. INSET: NASA/GSFC/ASU

METEOR WATCH | Full Moon interference

THIS MONTH'S FULL MOON falls within a day of the Oct. 21 peak of the Orionid meteor shower. Moonlight will effectively diminish the visibility of all shower meteors except for the brightest ones, so observed rates will be very low this year. The Orionid shower is directly linked to debris left over by the regular 76-year passages Halley's Comet.

The shower is active from Oct. 2 through Nov. 7, with much lower rates outside the night of maximum. A few Orionid meteors can be observed in the early morning sky the week before Full Moon — the best opportunity for spotting Orionids this year. For example, on Oct. 13, the First Quarter Moon sets around midnight, as Orion is rising. The dark sky will offer views of early shower members, but at much lower rates than the peak of 20 meteors per hour at maximum.

Orionid meteor shower



The Orionids' radiant in northeastern Orion rises after 10:30 P.M. local time.

ORIONID METEORS

Active dates: Oct. 2–Nov. 7
Peak: Oct. 21
Moon at peak: Full
Maximum rate at peak: 20 meteors/hour

STAR DOME

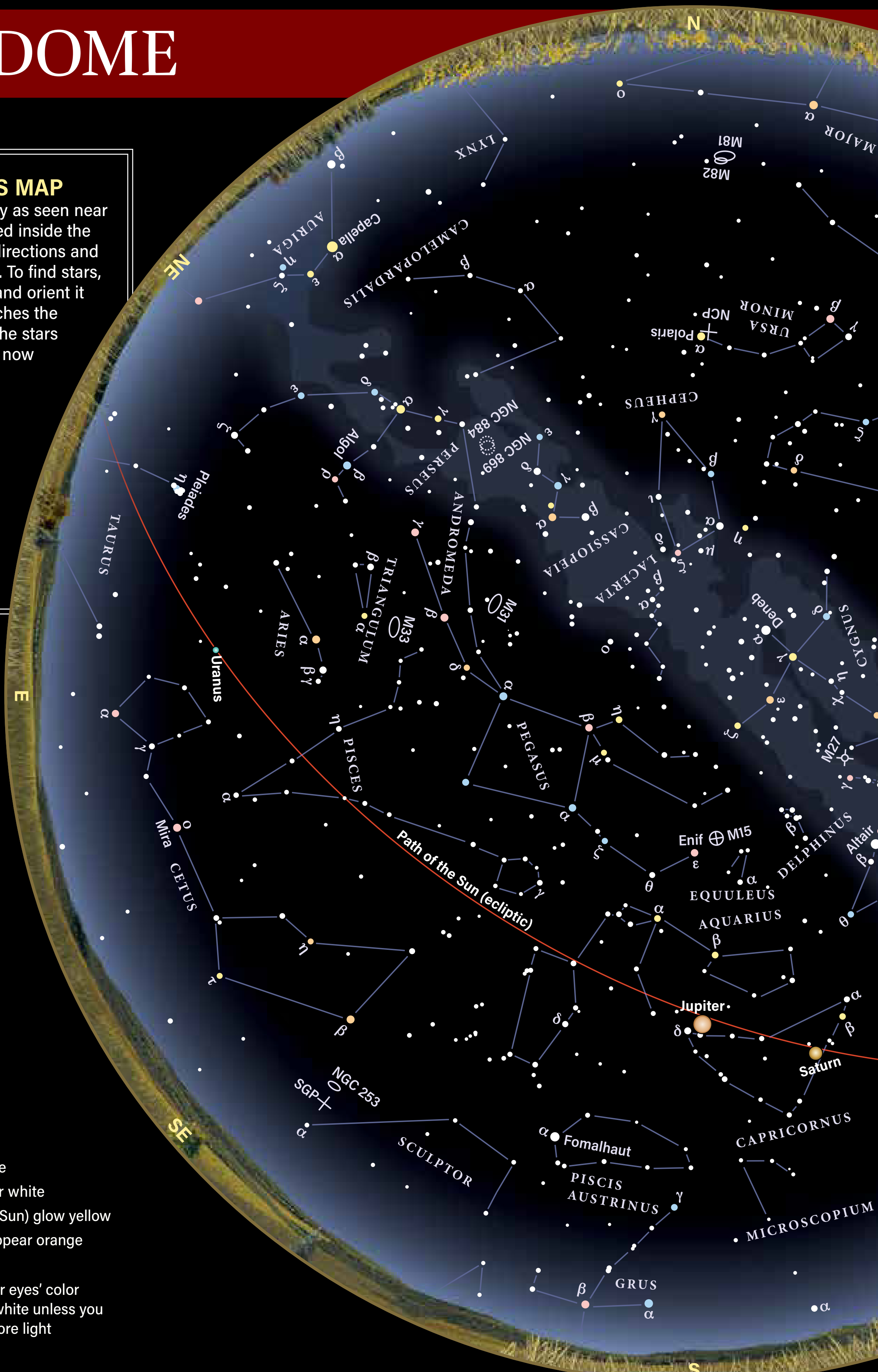
HOW TO USE THIS MAP

This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

10 P.M. October 1
9 P.M. October 15
8 P.M. October 31

Planets are shown at midmonth



MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

STAR MAGNITUDES

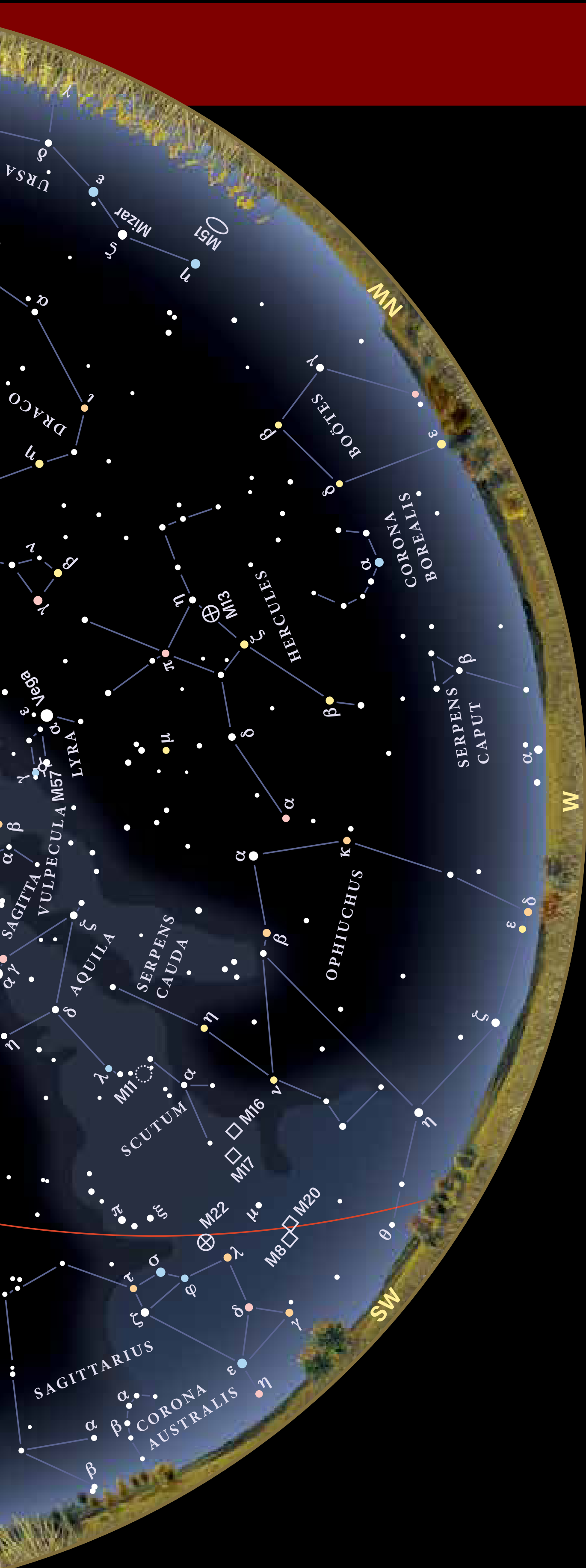
- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**



OCTOBER 2021

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31	Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.					

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

CALENDAR OF EVENTS

1 Asteroid Harmonia is at opposition, 3 P.M. EDT

6 New Moon occurs at 7:05 A.M. EDT

Pluto is stationary, 9 A.M. EDT

7 Mars is in conjunction with the Sun, midnight EDT

8 The Moon is at perigee (225,797 miles from Earth), 1:28 P.M. EDT

Dwarf planet Ceres is stationary, 3 P.M. EDT

9 Mercury is in inferior conjunction, noon EDT

The Moon passes 3° north of Venus, 3 P.M. EDT

10 Saturn is stationary, 10 P.M. EDT

12 First Quarter Moon occurs at 11:25 P.M. EDT

14 The Moon passes 4° south of Saturn, 3 A.M. EDT

15 The Moon passes 4° south of Jupiter, 6 A.M. EDT

16 Venus passes 1.5° north of Antares, 10 A.M. EDT

17 The Moon passes 4° south of Neptune, 10 A.M. EDT

Mercury is stationary, 9 P.M. EDT

18 Jupiter is stationary, 7 A.M. EDT

20 Full Moon occurs at 10:57 A.M. EDT

21 Orionid meteor shower peaks

The Moon passes 1.3° south of Uranus, 6 P.M. EDT

24 The Moon is at apogee (252,038 miles from Earth), 11:28 A.M. EDT

25 Mercury is at greatest western elongation (18°), 2 A.M. EDT

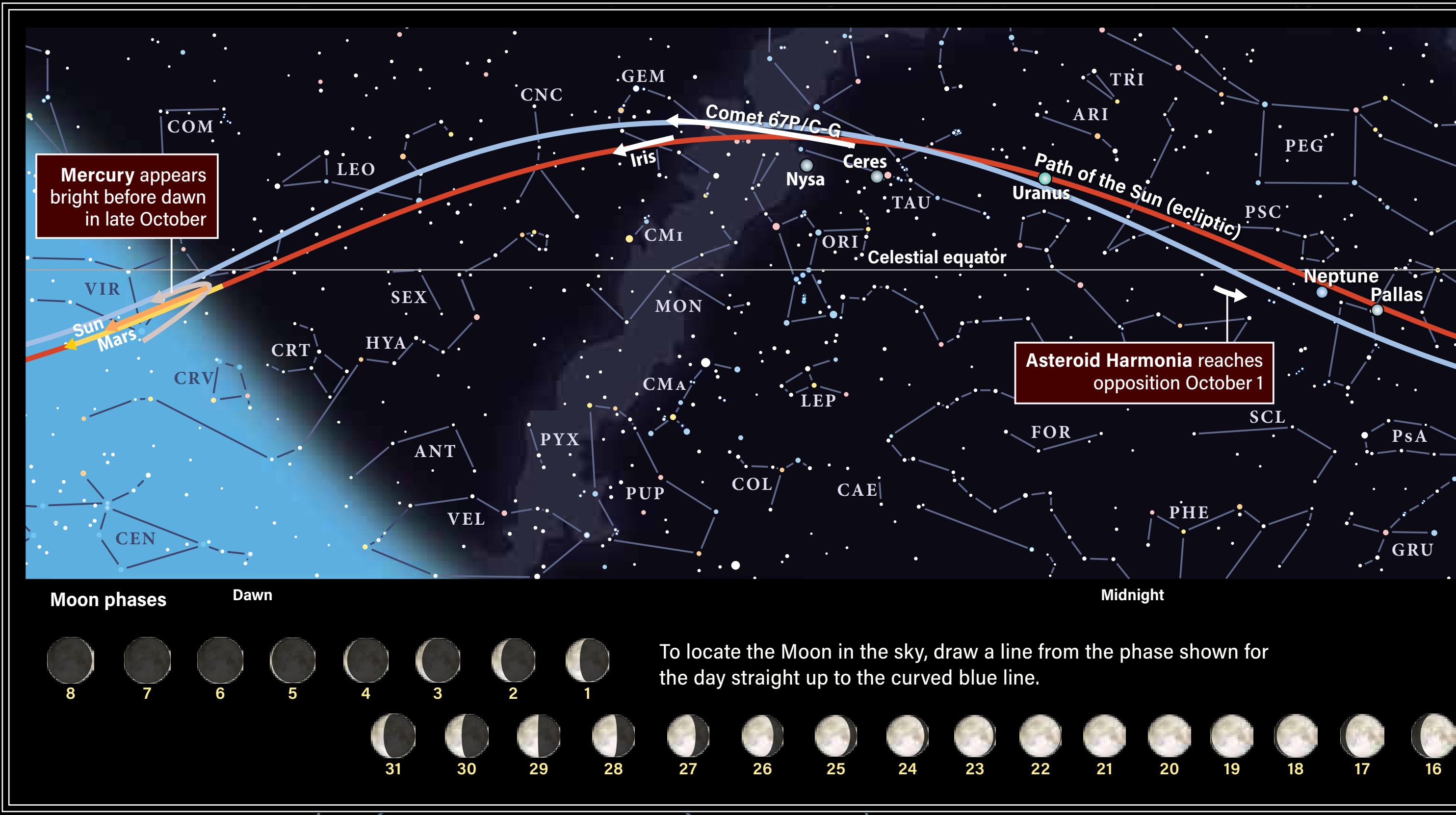
28 Last Quarter Moon occurs at 4:05 P.M. EDT

29 Venus is at greatest eastern elongation (47°), 5 P.M. EDT

31 Mercury passes 4° north of Spica, 10 P.M. EDT

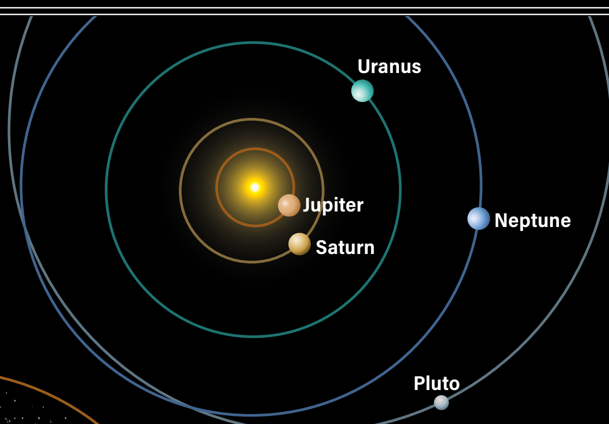
Asteroid Pallas is stationary, 10 P.M. EDT

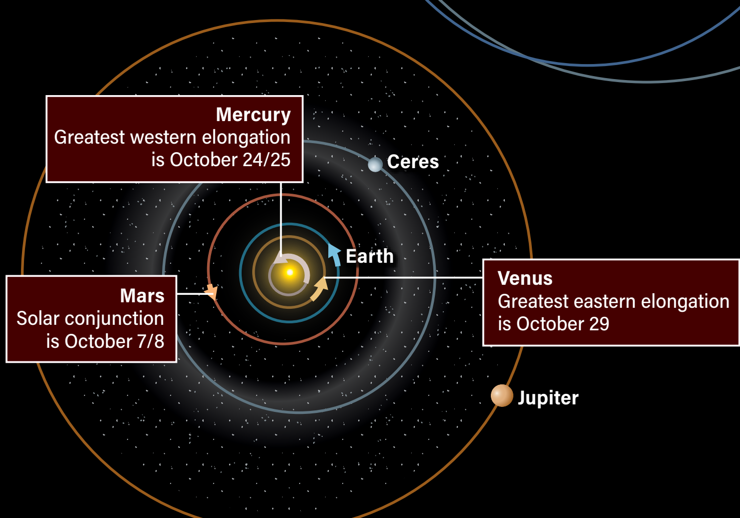
PATHS OF THE PLANETS



THE PLANETS IN THEIR ORBITS

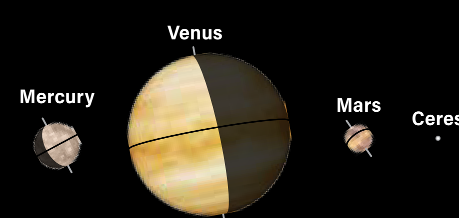
Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at midmonth from high above their orbits.





THE PLANETS IN THE SKY

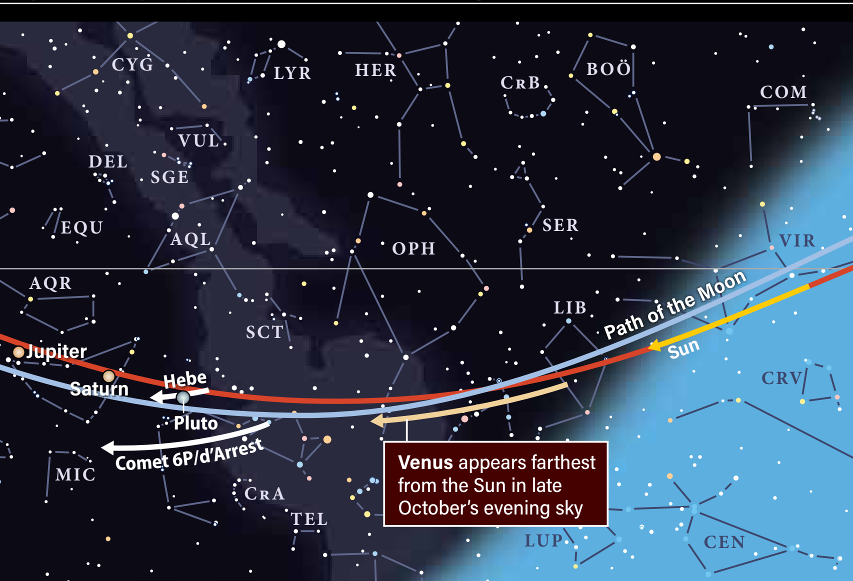
These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.



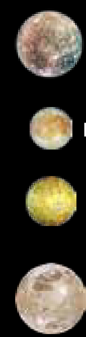
PLANETS	MERCURY	VENUS
Date	Oct. 31	Oct. 15
Magnitude	–0.8	–4.4
Angular size	6.0"	21.4"
Illumination	76%	56%
Distance (AU) from Earth	1.130	0.781
Distance (AU) from Sun	0.341	0.728
Right ascension (2000.0)	13h19.4m	16h22.2m
Declination (2000.0)	–6°06'	–24°37'

This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

OCTOBER 2021

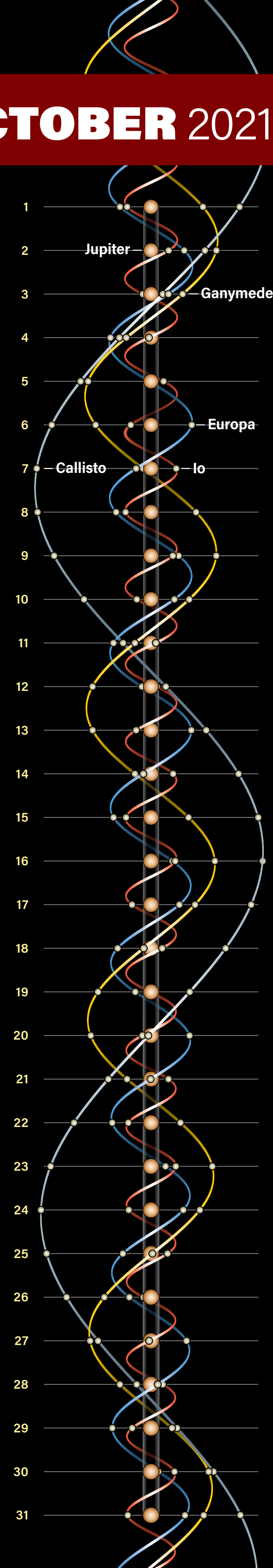


Early evening

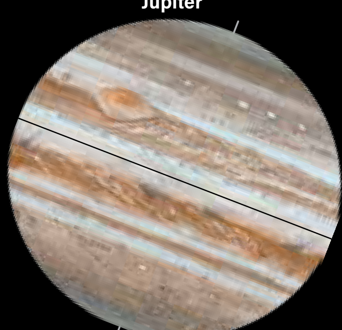


JUPITER'S MOONS

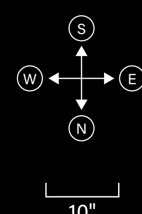
Dots display positions of Galilean satellites at 11 P.M. EDT on the date shown. South is at the top to match the view through a telescope.



Jupiter



Saturn



Uranus

Neptune

Pluto

MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Oct. 15	Oct. 15	Oct. 15	Oct. 15	Oct. 15	Oct. 15	Oct. 15
1.6	8.0	–2.6	0.5	5.7	7.7	15.2
3.6"	0.7"	44.5"	17.3"	3.7"	2.3"	0.1"
100%	98%	99%	100%	100%	100%	100%
2.619	2.038	4.430	9.630	18.804	29.062	34.325
1.624	2.782	5.011	9.936	19.734	29.922	34.382
13h12.2m	4h44.2m	21h39.2m	20h36.8m	2h44.0m	23h27.6m	19h44.9m
–7°00'	16°10'	–15°15'	–19°25'	15°26'	–4°46'	–22°56'

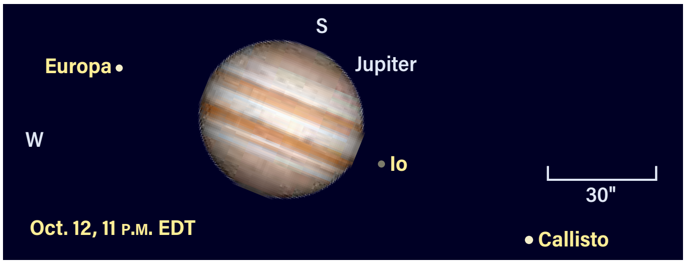
WHEN TO VIEW THE PLANETS

EVENING SKY
Venus (southwest)
Saturn (south)
Jupiter (southeast)
Uranus (east)
Neptune (east)

MIDNIGHT
Saturn (southwest)
Jupiter (southwest)
Uranus (southeast)
Neptune (south)

MORNING SKY
Mercury (east)
Uranus (west)

Musical chairs



Late on Oct. 12, Io is poised to emerge from Jupiter's shadow just as Callisto prepares to disappear within it. Europa will also pass behind the planet's disk. Ganymede lies farther west.

It stands 8' east of Saturn, 12 times farther than Tethys, also east of the rings the same night.

Saturn sets about 2 A.M. local time on Oct. 1 and just before midnight by Halloween.

Jupiter shines brilliantly in eastern Capricornus all month, dimming slightly from magnitude –2.6 to –2.5. Its retrograde path slows to a halt Oct. 18, a week after Saturn. Attentive skywatchers will see Jupiter's position relative to Deneb Algedi change slightly this month. It lies 1.8° northwest of the star Oct. 1 and moves to a point 2.1° northwest by Oct. 18. It then returns to within 1.9° of Deneb Algedi by Oct. 31. On Oct. 14 and 15, the waxing gibbous Moon lies nearby. The planet sets about 3:10 A.M. local time on Oct. 1, and by 1:15 A.M. on Oct. 31.

Jupiter is best viewed beginning in late twilight — when low-contrast views of its atmosphere are a sight to behold — and for a few hours into the evening, before it sets in the west after midnight. Any telescope reveals wonderful detail, from the planet's pair of dark equatorial belts to more subtle features to their north and south. Every few days, the Great Red Spot is also visible.

Observers can also catch the four Galilean moons. Their resonant orbits mean some events repeat during the month. For example, at 9:48 P.M. EDT on Oct. 5, Io comes out of eclipse by Jupiter's shadow, which stretches east of the planet. Europa is occulted by Jupiter's western limb 26 minutes later, at 10:14 P.M. EDT.

These events repeat Oct. 12/13, with a nice addition: Before Io comes out of eclipse, Callisto enters eclipse from an unusual location — farther from Jupiter than Io's position at reappearance. The reason is that at Callisto's greater distance from Jupiter, the planet's shadow extends farther east. Callisto begins to disappear at 11:11 P.M. EDT, followed by Io's reappearance at 11:43 P.M. EDT. Such events highlight the geometry of the jovian system. An hour later, at 12:40 A.M. EDT on the 13th, Europa dips behind Jupiter's western limb.

The Io/Europa pair performs a similar act early on Oct. 20. On Oct. 28, Io reappears from eclipse 6" northwest of Europa, just minutes after 10 P.M. EDT.

Neptune is a month past opposition and visible most of the night in Aquarius the Water-bearer. Binoculars will show the magnitude 7.7 planet well. Neptune begins the evening in the southeastern sky and reaches its highest point above the southern horizon before local midnight.

October opens with Neptune less than 4° east of magnitude 4 Phi (ϕ) Aquarii. The gap shrinks to 3.3° by Oct. 31. Look roughly 6.5° south of the Circlet in Pisces for a triangle of

COMET SEARCH | Crossing the plane

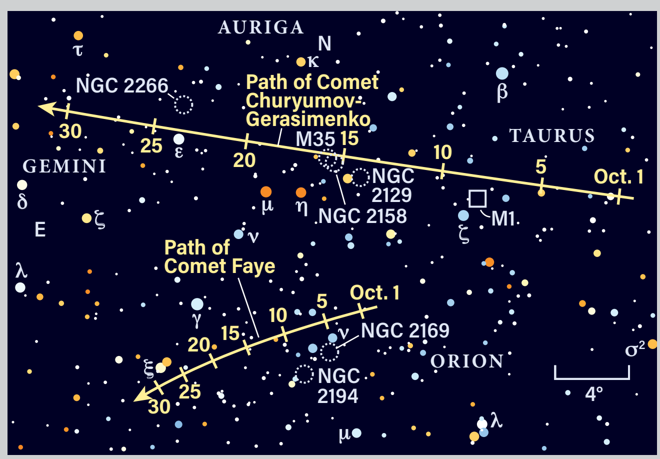
WE HAVE A MULTITUDE of 10th- to 11th-magnitude comets to choose from this month. The least erratic is 67P/Churyumov-Gerasimenko. Approaching as close to us as Mars, it receives a modest cooking from the Sun's rays, pouring out dust in a reasonably reliable way.

After midnight, find it following Aldebaran up the northeastern sky. On Oct. 8, it skims only 1° north of the Crab Nebula (M1). And your reward for waiting until moonset before dawn on the 16th is the comet posing with the splashy star cluster M35 in Gemini.

This snowball's soft glow will need a 4-inch scope under dark skies. An 8-inch aperture reveals the well-defined bow shock on the eastern flank, where the solar wind pushes back the dust. At month's end, Earth passes through the plane of the comet's orbit, giving us an edge-on view and a good chance at seeing a weak anti-tail, where the dust and ion stream poke out the other side.

Also don't miss 4P/Faye, cruising 8° to the south. It too gives us a plane crossing (on the 6th). About the same distance to Churyumov-Gerasimenko's northeast, perhaps C/2019 L3 (ATLAS) will be acting up. Meanwhile, 6P/d'Arrest swipes past globular cluster M55 in Sagittarius midmonth, but this small comet will be a pale fuzz in comparison.

Comet 67P/Churyumov-Gerasimenko



The rubber duck-shaped 67P/Churyumov-Gerasimenko, which the Rosetta mission orbited in 2015, is back. Alongside it are 4P/Faye to the south and C/2019 L3 (ATLAS, not shown) to the northeast.

Solo Mercury

By late October, Mercury is an easy naked-eye object in morning twilight.

6th-magnitude field stars; Neptune is west of this group all month. You can also use a pair of 6th-magnitude stars east of Phi in same binocular field of view. Draw a line from Phi through the midpoint of a line connecting these stars, and you're heading right for Neptune. The ice giant stands 7° west of a gibbous Moon Oct. 17.

Neptune currently spans 2". A telescope at high magnification on a steady night of seeing will show its bluish-green disk.

Uranus is approaching opposition, which occurs next month, and is visible nearly all night. In early October, wait a few hours after sunset to view it. Uranus lies about 16° west of the Pleiades, in a sparse region of southern Aries. It should be easy to spot at magnitude 5.7, especially with a handy nearby star to guide you. Uranus begins the month close to Omicron (ο) Arietis, which shares the planet's current magnitude. On Oct. 1, they are 23' apart. By Oct. 10, Uranus is less than 10' to the star's north. Uranus continues westward and lies a Full Moon's width west of Omicron by Oct. 24.

Omicron is 2.9° due north of 38 Arietis, which itself is 2.3° due north of 4th-magnitude Mu (μ) Ceti. Look for Mu in 7x50 binoculars before midnight and place it in the lower right of your field of view. 38 Arietis should be near the center of the field of view. If you're looking around midnight, instead place Mu at the bottom of your field of view. From Mu, move your binoculars to place 38 Arietis in the lower right and look for a 6th-magnitude double star — one of those "stars" is Uranus. Check each night and you'll easily spot the planet's motion.

Mercury reaches inferior conjunction with the Sun Oct. 9. You might imagine it will next cross in front of the Sun, but not this month. Such transits only occur when inferior conjunction is in May or November, when the planet's orbit crosses the ecliptic. Nov. 13, 2032, is the next time this happens.

Mercury skips into the morning sky soon after conjunction and is well placed before sunrise. The high angle of the ecliptic at dawn makes this the planet's best morning apparition for Northern Hemisphere observers this year. Mercury reaches greatest elongation (18°) Oct. 25. This is far shy of the possible 27°, due to the fact that Mercury reached perihelion just a week earlier, on the 19th. Observers with a clear eastern horizon might catch Mercury that day, shining at magnitude 0.4 and only 3.5° high an hour before sunrise.

Two days later, Mercury is much easier to spot. By Oct. 21, it's magnitude 0 and nearly 5° high an hour before sunrise. A week later, on Oct. 28, it has brightened to magnitude –0.7, an easy object with the unaided eye. Mercury brightens by another 0.1 magnitude through the end of the month and remains clearly in view each morning, even as its elongation from the Sun slowly diminishes.

Mars is too close to the Sun to observe this month. It returns to the morning sky by December.

Martin Ratcliffe *is a planetarium professional with Evans & Sutherland and enjoys observing from Wichita, Kansas.* **Alister Ling**, *who lives in Edmonton, Alberta, is a longtime watcher of the skies.*

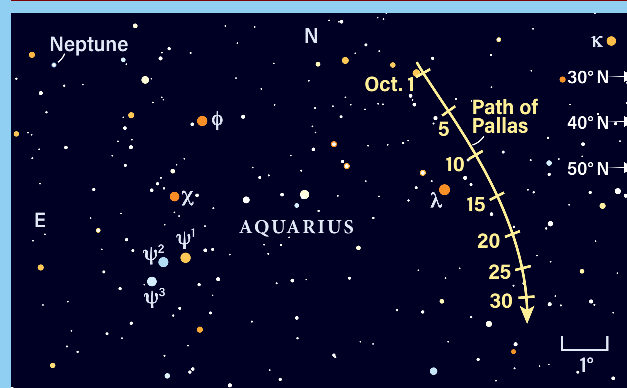
LOCATING ASTEROIDS | The tortoise and the hares

THE SECOND ASTEROID to be discovered, 2 Pallas happens to orbit on one of the most inclined paths of the main-belt family. Currently it is diving south through the ecliptic, the nearly flat racetrack of our solar system.

A 4-inch scope will let you track 9th-magnitude Pallas through the waters of Aquarius. Start at Saturn, pass straight through Jupiter for about the same distance, and you'll land on magnitude 3.7 Lambda (λ) Aquarii. Then scooch over a degree or two. The telltale sign of an asteroid is its night-to-night movement. For visual observers, the displacement is not enough to notice in a single session. Make a sketch of the starfield indicated by the chart and come back in another night or two to see which dot has shifted.

While you're gazing intently in the eyepiece, expect to be distracted by a slowly moving "star" that takes about four minutes to cross a 1°-wide field. We happen to be looking through the belt of geostationary satellites girdling our planet. The farther north you live, the farther south they appear to track on the sky. You might see half a dozen in a matter of 20 minutes.

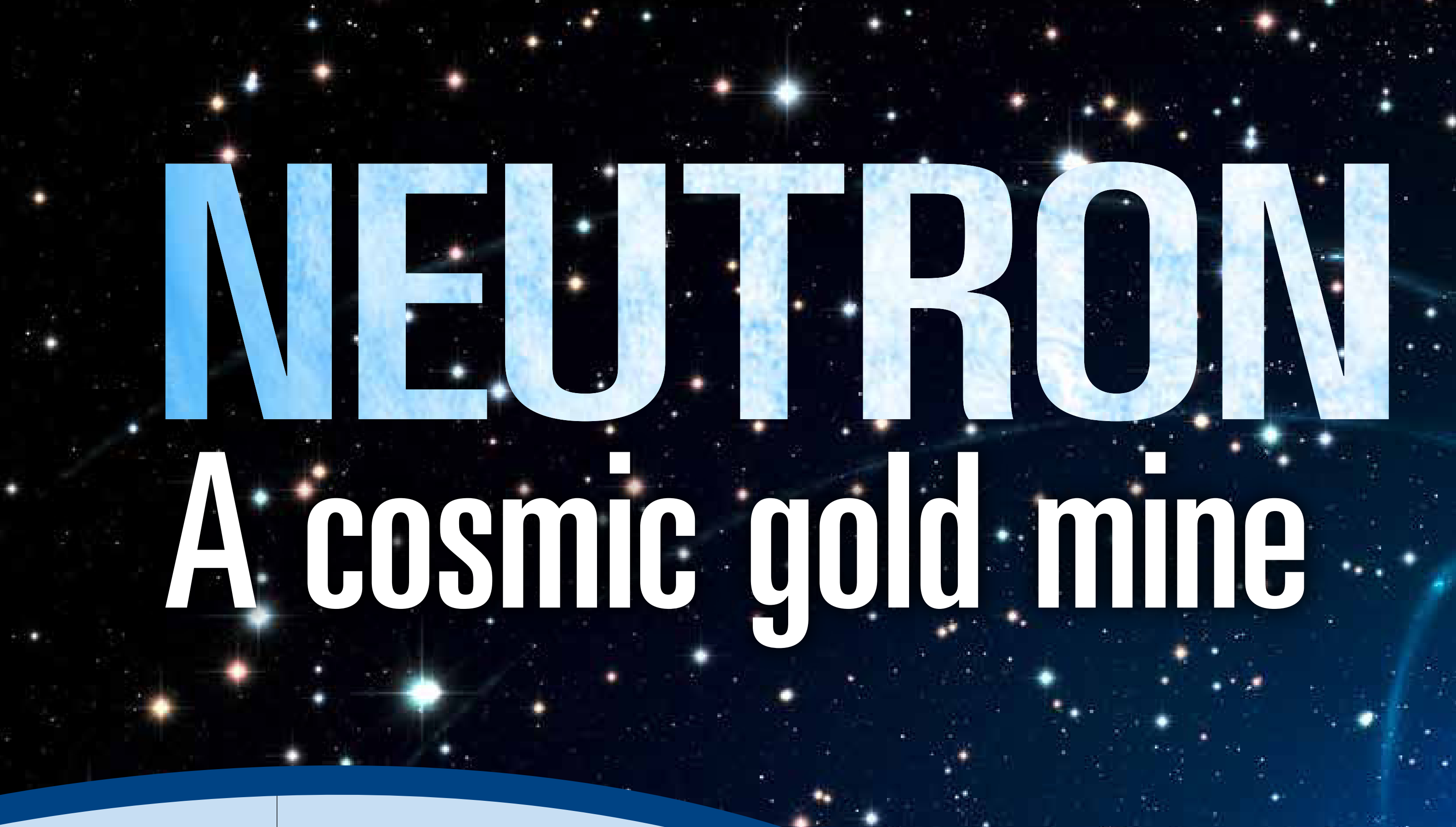
The bottom line



Pallas tracks through a region shared by geostationary satellites. Your latitude (denoted on this chart) will determine how far south these craft appear on the sky.

NEUTRON

A cosmic gold mine



Neutron stars are the perfect cosmic laboratory for the scientists who study them, thanks to their observability, extreme gravity, and strong magnetic fields. ESO/L. CALÇADA

IT ISN'T A SECRET THAT humanity and everything around us is made of star stuff. But not all stars create elements equally. Sure, regular stars can create the basic elements: helium, carbon, neon, oxygen, silicon, and iron. But it takes the collision of two neutron stars — incredibly dense stellar corpses — to create the heavier elements like silver, gold, and platinum.

Neutron stars aren't just notable for the valuable elements they create, though. They're also a dream come true for physicists. From their crushing gravity to the universe's strongest magnetic fields, extremes of physics are the norm for neutron stars. And, unlike black holes, these exotic objects are observable. "It's hard to study black holes," says Samar Safi-Harb, the Canada research chair in supernova remanent astrophysics at the University of Manitoba in Winnipeg, Canada. "With neutron stars, you can do a lot more. You can really probe the interior, there's a surface you can study, and you can measure a lot of its properties."

Creating a neutron star

Before you can get this ideal cosmic laboratory, a star first has to die. The end of a star's life depends largely on its mass. Unremarkable stars like the Sun go out with a relatively quiet whimper compared to their more massive cousins, whose deaths are announced with fireworks.

During most of their lifetimes, stars perform a careful balancing act between the inward force of gravity and the outward pressure caused by nuclear fusion in their cores. Eventually, however, a star will run out of material to burn. Stars like the Sun are limited to an initial hydrogen burning phase — the Sun's will continue for another 4 billion years — followed by a shorter helium burning phase of about 2 billion years.

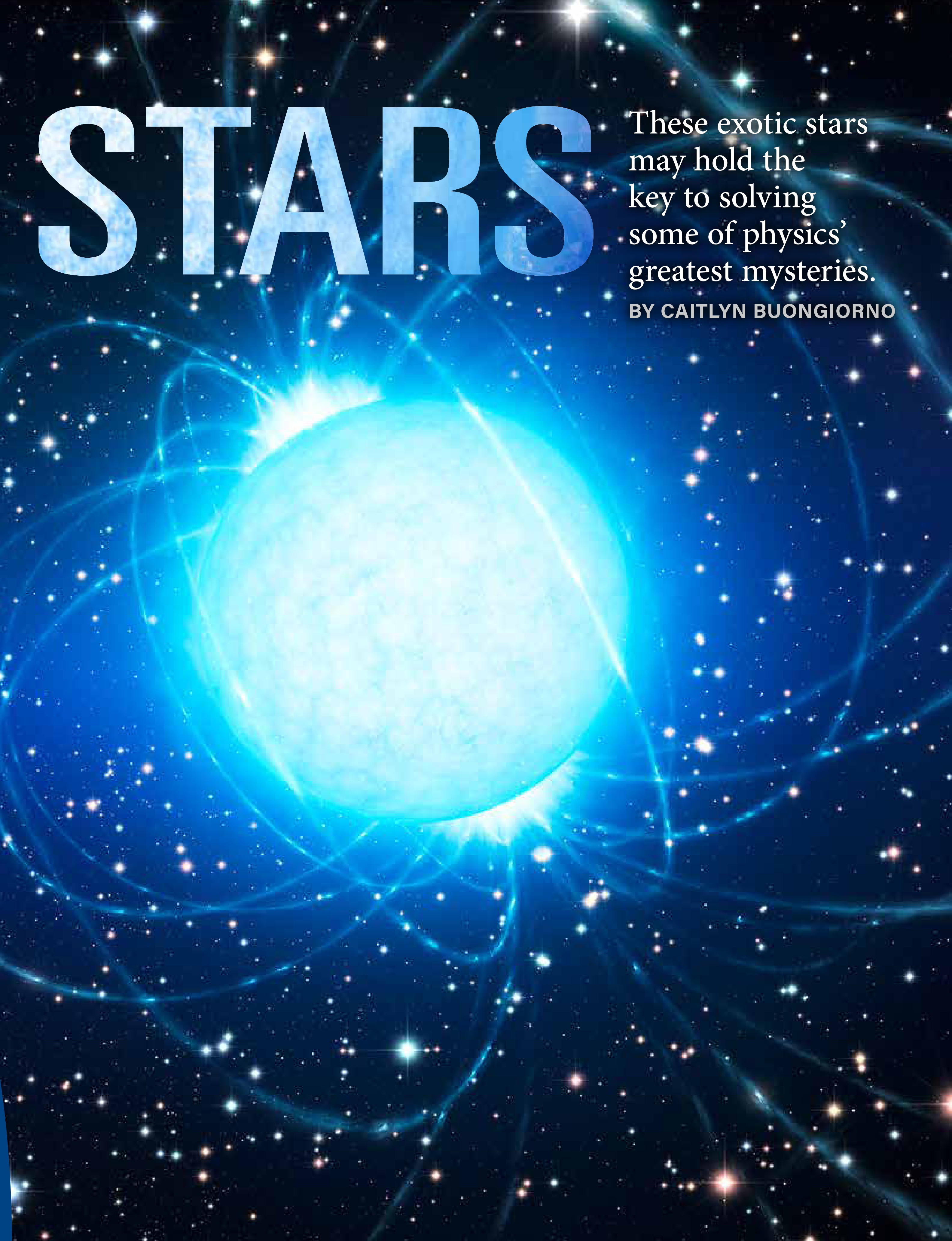
Massive stars, on the other hand, have many more phases, allowing for the nuclear fusion of hydrogen, helium, carbon, neon, oxygen, and, finally, silicon. After the silicon is gone, the star's core is composed of iron. Unfortunately for the star, however, no further energy can be gained from burning iron, so the process stops there. Once such a star runs out of fuel for nuclear fusion, the pressure pushing the star outward loses out and gravity quickly takes over. The star implodes, its outer layers collapsing inward.

At this point, the star's fate lies with the principles of quantum physics. Matter is composed

STARS

These exotic stars may hold the key to solving some of physics' greatest mysteries.

BY CAITLYN BUONGIORNO



Neutron stars contain about as much mass as the Sun squeezed into a space not much larger than a city like Munich, Germany, as shown in this artist's concept. ESO/ESRI WORLD IMAGERY, L. CALÇADA

of atoms, which in turn are made up of electrons, protons, and neutrons. All these particles are part of a special class of elementary particles known as fermions. These kinds of particles have a crucial property that comes into play when a star is imploding: Identical fermions cannot exist in the same place at the same time. This rule is called the Pauli exclusion principle.

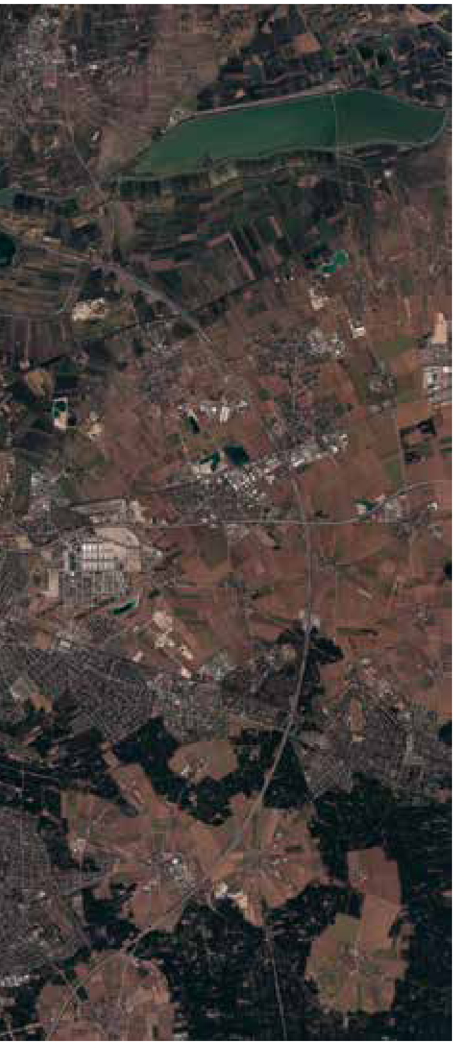
So, as the outer layers of the star are crushed into the core, the fermions in the star's center are packed together. The electrons orbiting the nucleus of an atom are the first to feel the squeeze. Unable to be forced any closer together, they produce their own kind of outward pressure, known as electron degeneracy pressure. This halts the progress of gravity, causing the material outside the core to be thrown off. The result is a white dwarf. Ultimately, stars like the Sun will end their life as these stellar remnants.

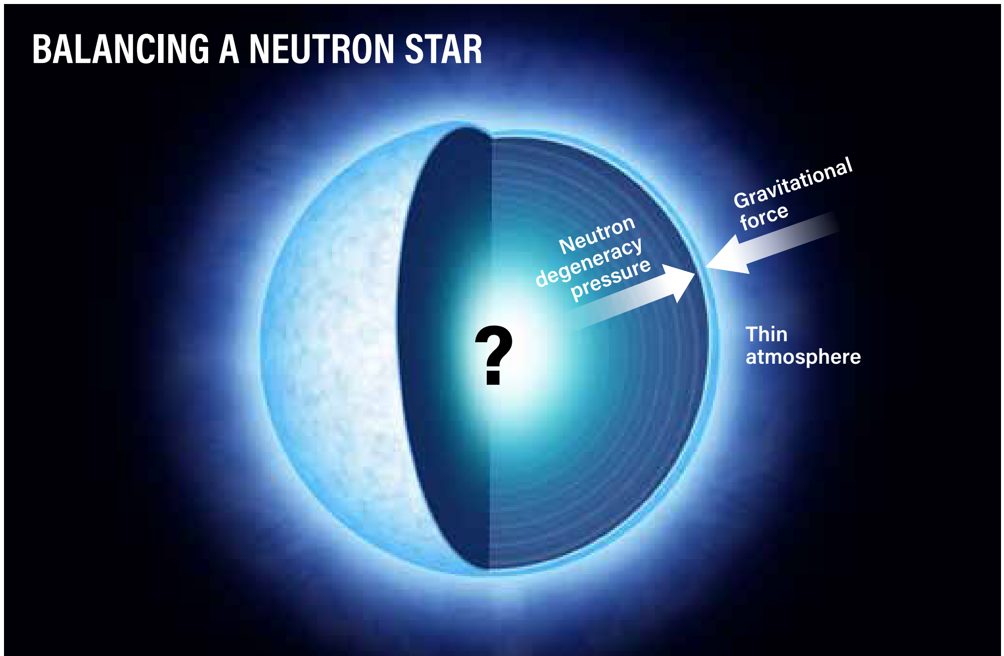
For more massive stars, however, gravity wins another battle here. The electrons are squeezed closer and closer to the neutron-proton core of their atom until they merge with the protons, creating more neutrons and some neutrinos. The neutrinos can zip out of the star freely, but the neutrons are crushed closer together until they exert their own gravity-fighting degeneracy pressure, creating a neutron star. In the most extreme cases, gravity overcomes even this force, winning the war and forming a black hole.

Neutron star basics

Similar to black holes, neutron stars were predicted to exist long before we observed them. In 1934, astronomers Walter Baade and Fritz Zwicky published a paper in the *Proceedings of the National Academy of Sciences of the United States of America* titled "Cosmic Rays from Super-Novae." They proposed that supernovae (a term they also coined) produce both the mysterious cosmic rays spotted coming from outside our galaxy and "the transition of an ordinary star into a *neutron* star." They further described these objects as "possess[ing] a very small radius and an extremely high density."

It took another 30 years for astronomers to discover the first neutron star. In 1967, Jocelyn Bell Burnell, an astronomy graduate student working for Antony Hewish at Cambridge University, spotted a weak, repeating signal





Neutron stars escape collapse into a black hole thanks to degeneracy pressure produced by their neutrons, which is able to fight the crushing force of gravity. What exactly lies at the heart of a neutron star, however, is unclear based on our current understanding of physics. *ASTRONOMY:* ROEN KELLY

using a large radio telescope at the Mullard Radio Astronomy Observatory. At first, Hewish and Bell Burnell wondered if they'd found proof of "little green men," but the two quickly dismissed that idea. Instead, they realized they had picked up on an unusual star exhibiting the exact characteristics Baade and Zwicky had proposed three decades prior.

Since the discovery, researchers have uncovered a whole menagerie of neutron stars with varying properties. But there are a few basic characteristics that these stars exhibit across the board.

Just as Baade and Zwicky predicted, neutron stars are incredibly small. The average neutron star has a diameter of roughly 12.5 miles (20 kilometers), or about the size of a city. And packed within that small volume is a Sun's worth of mass. Just one sugar-cube-sized block of neutron star material would weigh about 1 billion tons.

Those aren't the only extreme properties of neutron stars. They also spin at mind-boggling speeds. Thanks to a basic rule of physics — conservation of angular momentum — compact neutron stars can spin themselves up to a much higher rate than that of their progenitor star. Imagine a twirling figure skater. When their arms are outstretched, they spin slowly, but as they pull their arms in, they speed up. The same is true for stars. After a supernova, the remnant has a significantly smaller diameter and thus spins much faster than its progenitor. The fastest spinning neutron star, PSR J1748-244ad, makes 716 rotations per second.

Over time, however, like the figure skater, a neutron star's spin will peter out. This is thanks to the magnetic field that encircles the neutron star, which acts like an opposing force that ultimately puts the brakes on the star's rotation.

That effect isn't surprising, considering the strength of a neutron star's magnetic field, which is orders of magnitude greater than any other found in the universe. How exactly these objects generate such high magnetic fields isn't well understood. Like their spin rate, it's partially to do with the progenitor star's magnetic field being conserved when it collapses into a smaller object. But that effect alone isn't enough to explain the magnetic field strength seen in neutron stars.

While their magnetic field and spin may be extreme, neutron stars aren't very brilliant in visible light. Approximately 2,000 neutron stars have been identified in the Milky Way and Magellanic Clouds. At first, that may sound like a lot, but astronomers estimate there are a billion neutron stars hiding in our Milky Way alone.

There are a few reasons for this disparity. Most neutron stars are old. With only one supernova occurring in our galaxy every 50 years, that's not surprising. As they age, neutron stars cool down and fade in brightness, making them nearly invisible. But even young neutron stars can be difficult to spot. More often than not, astronomers have to rely on happy cosmic accidents to find a previously unknown neutron star.

Approximately 2,000 neutron stars have been identified in the Milky Way and Magellanic Clouds. At first, that may sound like a lot, but astronomers estimate there are a billion neutron stars hiding in our Milky Way alone.

Light from the supernova that created the Crab Nebula first reached Earth in A.D. 1054. Today, astronomers know that at its heart sits a pulsar spewing jets of matter and antimatter from its north and south poles. X-RAY: NASA/CXC/SAO; OPTICAL: NASA/STSCI; INFRARED: NASA-JPL-CALTECH

Pulsars: Testing the speed limit

One characteristic can make a neutron star easy to find. Many of them emit continuous beams of radiation from opposing hemispheres. And if the neutron star is spinning at just the right orientation relative to Earth, that beam may repeatedly sweep across our planet. This breed of neutron star is known as a pulsar — the class of objects that Bell Burnell discovered in 1967. When they spin, they look to radio telescopes like flickering stars in the night sky.

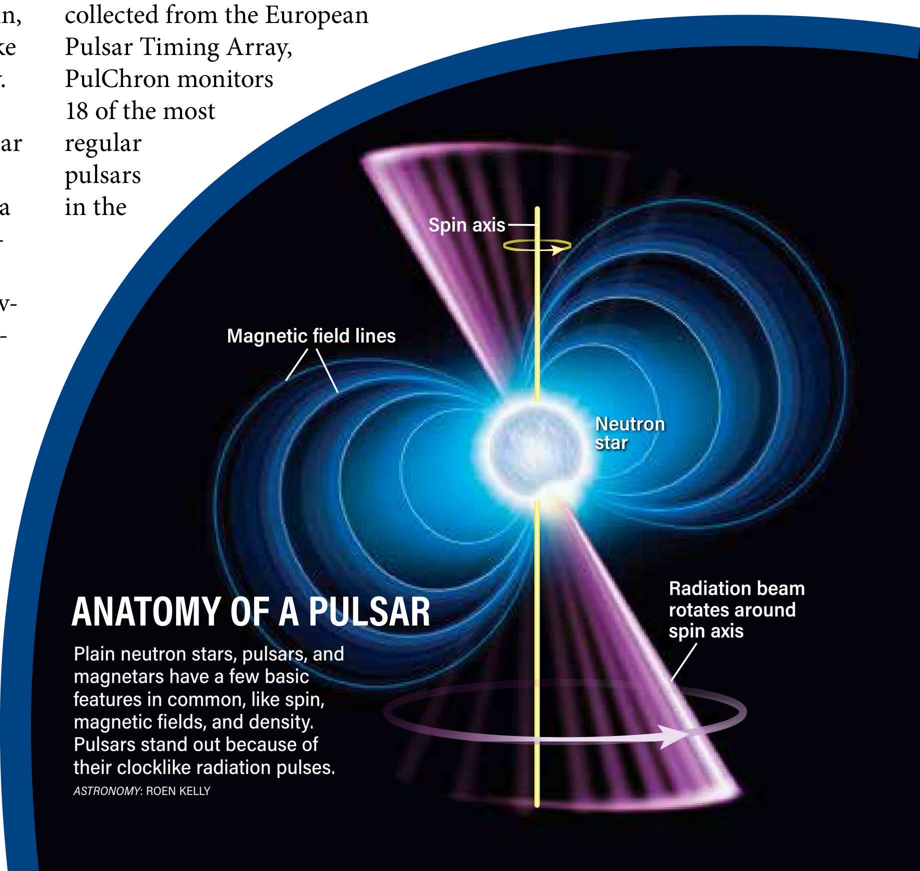
And boy, do pulsars spin. The fastest spinning neutron star — the previously mentioned PSR J1748-244ad — is actually a pulsar or, more precisely, a millisecond pulsar. These speedy pulsars get their name from having spin periods in the milliseconds, whereas normal neutron stars spin in the seconds range. The amped-up speeds of millisecond pulsars are likely thanks to a cosmic partner: A pulsar in a binary system can pull in material from its companion to "spin up" its rate of rotation into the millisecond range.

Typically, the radiation emitted from a pulsar tends to be at radio wavelengths; however, a few optical, X-ray, and gamma-ray pulsars have been discovered. The most famous example of an optical pulsar is the neutron star at the center of the Crab Nebula.

The timing of the pulses is incredibly predictable — so predictable that you could set your watch to them, literally. The European Space Agency has a project called PulChron to do just that. Using pulsar measurements collected from the European Pulsar Timing Array, PulChron monitors 18 of the most regular pulsars in the night sky. The large sample size helps to weed out any timing anomalies caused by passing gravitational waves, or ripples in the fabric of space-time, resulting from random cosmic events. According to the researchers, in the short term, atomic clocks — which keep time using the resonance frequencies of atoms — are better. But in the long term, neutron star clocks will outlive an atomic clock. Currently PulChron is used in conjunction with an active hydrogen maser atomic clock at the Time and Geodetic Validation Facility of Galileo.

Pulsars aren't just great for keeping track of time. Scientists think they can also be used to track Earth's motion through space. Groups like the North American Nanohertz Observatory for Gravitational Waves (NANOGrav), Australia's Parkes Pulsar Timing Array, and the European Pulsar Timing Array are training their eyes on a large number of well-understood millisecond pulsars to create a kind of gravitational-wave positioning system. Like a GPS unit on Earth uses satellites to determine your

The fastest spinning neutron star is actually a pulsar or, more precisely, a millisecond pulsar. These speedy pulsars get their name from having spin periods in the milliseconds, whereas normal neutron stars spin in the seconds range.



ANATOMY OF A PULSAR

Plain neutron stars, pulsars, and magnetars have a few basic features in common, like spin, magnetic fields, and density. Pulsars stand out because of their clocklike radiation pulses.
ASTRONOMY: ROEN KELLY

location, astronomers want to use pulsars to accurately determine Earth's position. The goal is to use that data to detect when gravitational waves pass through Earth and slightly alter its position. One of the sources of these Earth-altering gravitational waves could be the merger of two supermassive black holes. Living at the hearts of most galaxies, supermassive black hole mergers give off gravitational waves whose frequency is too low for the Laser Interferometer Gravitational-wave Observatory and Virgo collaborations to detect, but NANOGrav would be able to pick them up.

Magnetars: The more magnetic cousins

While pulsars may be the most reliable neutron stars, magnetars are the troublemakers of the family.

The magnetic field around a magnetar is about a thousand trillion times stronger than Earth's and often somewhere between 100 to 1,000 times stronger than a pulsar's. But a super-strong magnetic field doesn't come without its setbacks: "Magnetars are exploding, and you see gamma-ray bursts and X-ray bursts and crazy rotational anomalies," says Victoria Kaspi, a neutron star and radio transient researcher at McGill University in Montreal, Quebec.

Magnetars can also emit more pulsarlike emissions, but the difference between the two is clear to those that study them. "The radio emission is different, it looks different, it smells different," explains Kaspi. "In radio pulsars, it's like a lovely little pulse and it comes every time. But in magnetars it's like boom, *boom*, **BOOM**." So where pulsars are fairly predictable, emissions from magnetars are more random.

Besides being more erratic, magnetars are also more difficult to find than pulsars. Of the 2,000 neutron stars so far discovered throughout the Milky Way, only 31 are definitively classified as magnetars. So, little is understood about these exotic objects. But what we do know paints a pretty impressive picture.

In 2001, a mysterious radio signal passed over our planet, carrying in just 5 milliseconds as much energy at radio wavelengths as the Sun emits in an entire month. This fast radio burst (FRB) went unnoticed until 2007 and came from a source so far away it was impossible to even pin down. But when the next few FRBs struck Earth in 2013 and 2017, researchers were ready. Unfortunately, finding the cause

A NEUTRON STAR WITH AN IDENTITY CRISIS

X-RAY: NASA/CXC/UNIV. OF WEST VIRGINIA/H. BLUMER; INFRARED (SPITZER AND WISE): NASA/JPL-CALTECH/SPITZER

The youngest, fastest spinning magnetar — Swift J1818.01607, seen in X-rays (purple) in this composite image — is located about 21,000 light-years away.

NASA'S NEIL GEHRELS SWIFT TELESCOPE discovered the 31st magnetar, Swift J1818.01607 or J1818 for short, in March 2020. Researchers followed up with observations using NASA's Chandra X-ray Observatory. Aside from being the latest magnetar discovered, it turns out that J1818 is even more special: It is the youngest known magnetar, at a mere 500 years old. This gives researchers the opportunity to observe a time in a magnetar's life they've never seen before.

But its young age isn't the only unique aspect of J1818: The star is also the fastest-spinning magnetar, whirling around once every 1.4 seconds. And researchers say the magnetar's rotation rate is already slowing as it ages, meaning it likely started out spinning even faster.

And if J1818 wasn't already exotic enough, it also joins a group of only five known magnetars that act like pulsars. While magnetars typically emit lots of X-rays and gamma rays, J1818 was also observed giving off regular radio pulses. Curiously, J1818 initially appeared more pulsarlike than the four other known radio-loud magnetars. Whereas those objects emitted pulses that were bright across the radio-wave spectrum, a typical pulsar — and J1818 — is brighter at longer wavelengths.

While astronomers watched it between June and July 2020, J1818 flickered between pulsarlike and magnetar-like radio pulse emissions. Over the course of 15 days, it settled down into a permanent magnetar-like state. *— C.B.*

NEUTRON STARS, KILONOVAE, AND MAGNETARS, OH MY!

WHEN STARS COLLIDE, the result is often explosive. That's especially true when they are a pair of superdense stellar remnants like neutron stars. The fireworks show, called a kilonova, unleashes more energy than the Sun will produce during its 10-billion-year lifetime. Kilonovae shine as a result of the radioactive decay of heavy elements — like gold and platinum — that are produced during the merger and blasted outward. These events last less than two seconds and produce short gamma-ray bursts.

And wouldn't you know it, the light from one such collision reached Earth on May 22, 2020. After traveling nearly 5.5 billion light-years, the brilliant flash was first detected by NASA's Neil Gehrels Swift Observatory. Then, telescopes across the world quickly turned their eyes to the aftermath of the explosion.

As the most luminous kilonova event on record, the find was already groundbreaking, resulting in some of the most detailed observations to date. But data from the Hubble Space Telescope took that even further. When light from this event, GRB 200522A, reached Earth, Hubble observed the event across the across a broad swath of the electromagnetic spectrum, finding the event's infrared emissions 10 times greater than predicted. The most likely explanation, researchers say, is that the remnant of the collision was feeding energy into the emission.

"We don't know the upper mass limit of neutron stars and the lower mass limit of black holes," says Wen-Fei Fong of Northwestern University, lead author of the study. "But if you take two neutron stars and smash them together — and you assume most of that mass ends up in the new object — then more than likely you're going to be in the regime of black holes." But not all of that mass is going into that new object, making it possible to instead form a so-called heavy neutron star. These heavy neutron stars are thought to be unstable, collapsing into a black hole in a handful of milliseconds.

Researchers suspect that the collision formed a heavy magnetar, creating the perfect storm to power the resulting kilonova. A magnetar's magnetic field lines whipping around can deposit some of the rotational energy from the newly formed object into the ejecta, causing that material to glow brighter than expected.

If true, this will be the first time researchers have seen evidence of merging neutron stars giving birth to a magnetic monster. In order to know for certain, scientists will have to keep their eyes trained on this area of the sky. If a magnetar really is lighting it up, then within a few years, the ejected material from the burst will begin appearing in radio wavelengths.

"If we hadn't looked with the right telescopes, we would have never known this was a weird feature," says Fong. "I've been studying short gamma-ray bursts for over 10 years now, and I'm just amazed that [the universe] never ceases to throw surprises our way. So, I'm excited for when we start detecting more of these [gamma-ray] sources." — *C.B.*

A binary pair of neutron stars begin their gravitational death dance in this artist's concept. Gravitational waves ripple across the fabric of space-time as they swirl closer and closer. UNIVERSITY OF WARWICK/MARK GARLICK

Their merger is celebrated by a brilliant kilonova, producing short gamma-ray bursts and heavy elements such as gold and platinum. ESO/L. CALÇADA/M. KORNMESSER

of FRBs still proved to be a challenge. Although astronomers could track the 2017 signal back to a galaxy some 3 billion light-years away, most FRBs are too sudden and random to pin down more precisely.

Models suggested that magnetars could be the culprits behind FRBs. But the magnetars observed in our galaxy had never exhibited behavior that would suggest these remnants could be capable of launching FRBs energetic enough to reach us from across the universe. To track down a Milky Way FRB, researchers trained their eyes on a single magnetar, SGR 1935+2154. And it did not disappoint. In early 2020, Earth caught a glancing blow from an FRB launched by this object. This detection cemented the connection between FRBs and magnetars, although there is still room for other objects to also cause FRBs.

Missing puzzle pieces

Despite their ability to tell us about the universe around us, there's plenty researchers don't understand about neutron stars themselves.

For starters, we don't even have a close-up image of one. In 2019, the world was taken by storm when the Earth-spanning Event Horizon Telescope released the first image of a black hole's shadow. Its target was the solar system-sized supermassive black hole at the heart of M87, which lies 54 million light-years away. But even though the nearest neutron star, RX J185635-3754, is only 200 light-years distant — significantly closer than M87

— it's still too tiny to get an up-close image of with our current telescopes. "Neutron stars are just 10 to 15 kilometers [in diameter] no matter what, so it's very hard to image such an object," says Safi-Harb.

Scientists also have no idea what neutron stars' interiors look like. That's because physics predicts that deep inside the cores of neutron stars, the pressure exerted by gravity is too strong even for degenerate neutrons to withstand.

Neutron stars, like normal stars, are composed of layers. It's easiest to think of them as consisting entirely of neutrons, but that isn't actually the case. Astronomers believe neutron stars have a thin layer of atmosphere composed of hydrogen and helium. Beneath that lies a thin layer of outer crust — less than an inch thick — containing electrons unattached to a nucleus and atomic nuclei. In the inner crust, those electrons and nuclei become packed together. Some of the electrons combine with protons in lighter nuclei to make neutrons, while heavier atomic nuclei are spared. The outer core is where the neutron-rich environment begins. And beyond that is the inner core, whose composition physicists can only guess at.

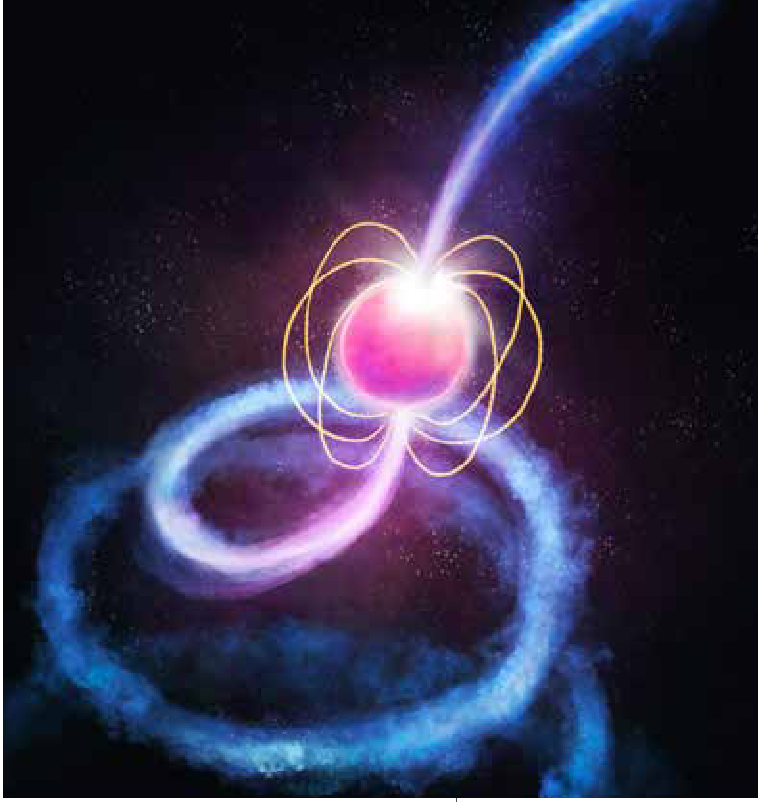
"Once you get to the core of the neutron star, something has changed there. The density there is too high for this [neutron degeneracy pressure] picture [as we understand it]," says Kaspi. Some theories point to pressure from quarks — the particles that make up protons and neutrons — as the force holding up the inner core. Alternatively, a new particle might be responsible. Figuring out exactly which model holds up requires more data, however.

One way to rule out some of those models is to find more massive neutron stars. "For every model, there is some maximum mass above which it collapses into a black hole," says Kaspi. And astronomers don't quite know yet where the boundary between black holes and neutron stars lies. The most massive neutron star, PSR J0740+6620, is 2.1 solar masses, whereas the smallest black hole found, dubbed the Unicorn, weighs in at 3 solar masses.

In 2017, astronauts deployed the Neutron star Interior Composition Explorer (NICER) on to the International Space Station. NICER is the first dedicated neutron star mission and is therefore, according to Safi-Harb, "the best experiment to address the question [of what is at the heart of a neutron star]."

Understanding what's going on at the core of a neutron star would also help explain what's going on outside as well — namely, with its magnetic field. Originally, theorists believed that the magnetic fields around neutron stars were mostly dipoles, with the north and south sides emerging from opposite sides of the object. But recent observations have revealed that they aren't that simple. Take the pulsar J0030+0451, which was observed by NICER in 2019. Based on those observations, simulations predict the possibility of two or even three separate magnetic fields emerging from the southern hemisphere of the object alone.

Though mysteries abound when it comes to neutron stars, astronomy is entering a golden era. And thanks to the LIGO/Virgo collaborations, researchers have a new tool in gravitational waves to study the cosmos with. LIGO has managed to capture just two binary neutron star mergers, but scientists are hopeful the observatory will discover more in the coming years.



This artist's impression shows a pulsar — a dense and rapidly spinning neutron star — sending radio waves into the cosmos.
ICRAR/CURTIN UNIVERSITY

"There are a lot of big telescopes being built across the electromagnetic spectrum," says Safi-Harb. "It is the synergy of all these telescopes together with gravitational waves that I'm most excited about, because there will be room for lots of discoveries and surprises that we didn't even anticipate."

And with each new neutron star discovered, astronomers are learning more about these compact objects, including that the neat categories they expected are more like a sliding spectrum. Some magnetars have been observed to exhibit more pulsar-like behavior and vice versa. Even stranger, the Chandra X-ray Observatory discovered what researchers are calling anti-magnetars. They appear to be neutron stars with uncharacteristically low magnetic fields. In the past decade, about two dozen of these strange objects have been found at the heart of supernovae remnants.

"This is why I do this kind of astronomy," says Kaspi. "Neutron stars are just really cool."

Caitlyn Buongiorno *is associate editor of* Astronomy.

Scientists also have no idea what neutron stars' interiors look like. That's because physics predicts that deep inside the cores of neutron stars, the pressure exerted by gravity is too strong even for degenerate neutrons to withstand.

Looking for galaxies IN ALL THE wrong places

Despite battling copious dust and crowded star fields, observing galaxies through the Milky Way is well worth the effort.

BY ALAN GOLDSTEIN

JOHNNY LEE SANG ABOUT looking for love in all the wrong places. But unlike the travails of poor Johnny, whose lifetime spent in singles bars yielded no traces of what he was dreaming of, in astronomy, searching for cosmic objects in unexpected locations is no fool's game. After all, space is big, and a galaxy being in the "wrong place" simply means that an observer might not expect it to be there. It's really a matter of perspective. For instance, if our Sun were located somewhere else in the Milky Way, even our galactic neighbor, the expansive Andromeda Galaxy, could be entirely hidden from our view, its light blotted out by our own galaxy's plane of dust, gas, and stars.

Galaxies are the building blocks of the cosmos, and they are distributed relatively uniformly across the sky. Yes, there are concentrations known as galaxy clusters and there are places that don't hold many bright examples. But no telescopic fields away from the dense hub of the Milky Way are entirely devoid of galaxies.

There are plenty of galaxies "through" or near the Milky Way, too. The problem with viewing the latter group is that it's not always easy to get a good look at them.

There are three factors that make observing galaxies in and around the band of the Milky Way challenging. First is something called *extinction* — the dimming of distant objects that occurs when some of their photons are intercepted and absorbed by molecules of interstellar dust. Our galaxy's central disk is crowded with stars and gas, but it's the Milky Way's prolific dust that really makes observing distant galaxies so difficult.

The amount of extinction an observer experiences is directly proportional to how much of the Milky Way they are looking through. Typically, for every kiloparsec (3,262 light-years) of Milky Way your visual path cuts through, the distant object you're targeting will appear about 1.8 magnitudes fainter. So, in general, the closer a galaxy is positioned to the galactic plane, the dimmer it looks. A distant galaxy near the galactic plane will also appear redder — a phenomenon called *reddening* — due to blue light being preferentially absorbed and scattered by the Milky Way's dust. The best examples of this are the extinction-plagued galaxies Maffei 1 and Maffei 2 in Cassiopeia. They are only a few degrees from the galactic plane and were only discovered in 1967 using specialized, hypersensitive photographic plates with the 36-inch Schmidt telescope at Asiago Observatory in Italy.

A second factor that makes seeking galaxies near the Milky Way's plane a challenge is the abundance of foreground stars. For example, compare the star fields around M87 in Virgo to those around the Eagle Nebula in Sagittarius — the difference in the richness of foreground stars is obvious. Teasing out the fuzzy glow of a galaxy is difficult when clumps of stars intrude on your field of view. Have you ever been stymied by a nebulous patch that you think is your target, then higher magnification resolves it to a glimmering point or a

Fisheye view of the Milky Way
This 360° panorama of the autumn sky and the Milky Way was captured on a late September night from a very dark site at Red Rock Canyon in Waterton Lakes National Park, Canada. The shot was illuminated solely by starlight. (The Milky Way's galactic center is toward the southwest at left.) ALAN DYER

↑ Maffei 1 and Maffei 2

The galaxies Maffei 1 (right) and Maffei 2 (left) are both visible in this long exposure captured from Dardenne Prairie, Missouri, in November 2016. Due to the galaxies' locations behind the Milky Way's arm, they both suffer from heavy extinction and are highly reddened. DAN CROWSON

← NGC 6946

The photographer captured this beautiful view of the Fireworks Galaxy using a Celestron 11-inch EdgeHD telescope set up in their backyard in upstate New York on June 18, 2020. Fortunately, even more modest telescopes can reveal many of the subtle features of this striking face-on galaxy. NATHAN DUSO

moment of steady air brings several close, faint stars into sharper focus? You are more likely to encounter these false alarms as the density of field stars increases. Galaxies near the limit of your telescope will already be a challenge, and abundant field stars only exacerbate the problem.

The third factor is that, by chance, there simply aren't many intrinsically bright galaxies near our galactic plane. For this reason, galaxy hunters may stay away from the glow of the Milky Way altogether. It's convenient to observe where the galaxies are most readily abundant and apparent: well above and below the galactic plane. But, eventually, won't you want to challenge yourself? So why not look for a galaxy where you don't expect to find one?

None of these recommended targets are easy to observe with small telescopes of roughly 2 to 4 inches in diameter. But most can be seen with an 8-inch scope under night skies that are free of light pollution. This selection is spread over the seasons and spans our Milky Way over many galactic longitudes.

FEATURED GALAXIES

NAME	CONSTELLATION
NGC 6946	Cepheus
Maffei 1, IC 10	Cassiopeia
NGC 7231	Lacerta
UGC 11466, NGC 7013	Cygnus
NGC 6822, NGC 6841	Sagittarius
NGC 6921	Vulpecula
NGC 2341, NGC 2342	Gemini
NGC 2350	Canis Minor
NGC 2380	Canis Major
NGC 2559, NGC 2566	Puppis
NGC 2119	Orion

Worthwhile targets

Let's begin with the brightest: **NGC 6946**. Sometimes called the Fireworks Galaxy because of its abundance of supernovae, this near-face-on Sc spiral can be a challenge because of its orientation. Face-on means you are seeing the galaxy's disk from "above," looking through a thin swath of the galaxy's stars. But a modest aperture can still reveal NGC 6946's spiral arms and more subtle features like regions filled with ionized hydrogen (HII regions), which are indicative of massive, young stars nearby. This isn't the galaxy nearest the galactic plane on our list, so it shows more detail than many others featured here.

The most highly reddened galaxy on this list is the previously mentioned **Maffei 1**, located only 0.55° from the galactic plane. Astronomers estimate this galaxy suffers from about 4.7 magnitudes of extinction. It is an observing challenge requiring a 12-inch scope and very dark skies. If it were located any farther from the outer rim of the Milky Way, Maffei 1 wouldn't be visible at all, even in infrared wavelengths.

IC 10 is an irregular galaxy in Cassiopeia. A member of the Milky Way's Local Group of galaxies, it is faint, but bears magnification well. A large telescope will display its patchy nature. IC 10 is the only starburst galaxy in our galactic neighborhood. Like typical irregular galaxies, IC 10 lacks a central hub of older stars, although it has an HII region in its core. Its magnitude of 10.4 makes it sound easier to observe than it is, but with large optics, you can bring out its mottled texture.

A somewhat less challenging galaxy

IC 10

A member of the Local Group, IC 10 is classified as a dwarf irregular galaxy. It lies near the galactic plane of the Milky Way, which means that copious interstellar material leads to extinction. Older stars are responsible for the galaxy's yellow and green, while the red filaments are Hydrogen-alpha (Hα) regions that sport active star formation. MICHAEL A. SINISCALCHI

NGC 2342

Using data from the Hubble Space Telescope, this up-close view of NGC 2342 seems to show a galaxy bursting with star formation, which might be the result of it gravitationally interacting with a neighboring galaxy, NGC 2341 (not pictured). NASA/ESA, S. HENDRIX

NGC 6822

A barred irregular galaxy, NGC 6822 (Caldwell 57, IC 4895) is located approximately 1.6 million light-years away in Sagittarius. Part of the Local Group, the galaxy resembles the Small and Large Magellanic Clouds, which are satellite galaxies of the Milky Way. This view of NGC 6822 was captured October 2014 at the All-Arizona Star Party in Salome, Arizona. DAN CROWSON

in the compact Milky Way constellation Lacerta is **NGC 7231**. At magnitude 13, this highly inclined barred spiral is visible using a 6- to 8-inch telescope under dark skies. It is located about 0.3° southwest of a 5th-magnitude field star and about 2° southeast of the large open cluster NGC 7209.

UGC 11466 was one of the first anonymous galaxies (those not found in the NGC or IC catalogs) that I ever observed. The constellation Cygnus holds only one famous galaxy: Cygnus A, which is radio bright but visually faint. However, Cygnus also contains several other galaxies that are visible with moderate-sized telescopes. UGC 11466, which is positioned very close to Delta (δ) Cygni, is particularly easy to find. At magnitude 12.7, it appears as a smooth oval glow in a rich starfield through large scopes. Perhaps it will be your first anonymous galaxy too.

Staying in Cygnus, how many times have you observed the Veil Nebula? Did you know there is a galaxy located only 2° to the Veil's southeast? **NGC 7013** is an edge-on spiral or lenticular galaxy that glows at magnitude 12.4 and spans some 4'. It lies about 2° southeast of NGC 6995. A bright field star resides at its northern end. This obscure object has a compact core, a small hub, and a disk with relatively low surface brightness for an edge-on galaxy.

NGC 6822 is known as Barnard's Galaxy, and that's because E.E. Barnard's early photographic efforts uncovered it in 1884. Like IC 10, Barnard's Galaxy is a member of our Local Group, located only 1.6 million light-years away. This dwarf irregular has an unusually large number of HII regions and, under dark skies, is a good target even for small scopes. Larger optics may reveal some of these gas clouds.

NGC 6841 is located 4° west-southeast of the large globular cluster M55 in Sagittarius. This relatively obscure elliptical is a small, round, 12.4-magnitude glow that is visible with modest telescopes. With increased aperture (12 inches and larger), make sure to seek out two near-14th-magnitude anonymous galaxies in the same field: ESO 461-24 and ESO 461-25.

The constellation Vulpecula may be best known for the Dumbbell Nebula, a large and bright planetary nebula. But the tiny constellation also has some worthwhile galaxies. Tucked away near its border with Delphinus and on a line midway between Zeta (ζ) Cygni and Gamma (γ) Sagittae is **NGC 6921**. This edge-on galaxy faintly glows at magnitude 13.5, so it needs to be targeted from a good dark-sky location. It has a fainter anonymous companion in the same field of view.

Although the winter Milky Way doesn't have the bright star clouds of Cygnus, Scutum, and Sagittarius, there are plenty of nebulae and clusters to target. Yet, finding galaxies can challenge the northern observer as much as braving the cold weather. Fortunately, a nice pair of faint galaxies resides (appropriately enough) in the constellation Gemini the Twins. **NGC 2341** and **NGC 2342** are an interacting duo of Sc galaxies that glow at magnitude 13. NGC 2341 has

↑ NGC 2559

The kinked and scrambled structure of NGC 2559 is visible in this beautiful shot captured using the remotely operated ChileScope Observatory in the Chilean Andes. An amateur telescope might not bring out this much detail, but targeting the galaxy with any scope rarely disappoints. RUSS CARPENTER/CHILESCOPE

↑ NGC 2380

Easily mistaken for a planetary nebula within the Milky Way, the lenticular galaxy NGC 2380 is really located some 28 times farther away than the Andromeda Galaxy. DONALD PELLETIER USING PUBLIC DATA FROM PAN-STARRS

↑ NGC 2566

NGC 2566 (bottom) is a barred spiral galaxy located approximately 73 million light-years away in the constellation Puppis. Also visible in this image — created from multiple exposures taken between December 2016 and January 2017 at the dark-sky site of Rancho Hidalgo in New Mexico — is the elliptical galaxy IC 2311 (top), located some 84 million light-years away. DAN CROWSON

slightly distorted arms and a faint bridge leading toward NGC 2342, which only reveals itself in deep images.

Located only 10° above the galactic plane and 7° from the Cone Nebula complex, **NGC 2350** is a highly inclined lenticular galaxy near the Canis Minor/Gemini border that shines at magnitude 12.3. To find it, trace a line from Procyon (Alpha [α] Canis Minoris) to Gomeisa (Beta [β] Canis Minoris) and extend that line an additional 4.5°.

NGC 2380 lies 2° north of Eta (η) Canis Majoris. It is a large class SB0 lenticular galaxy and, at magnitude 11.5, is also relatively bright. Located about 6° south of the galactic equator, NGC 2380 inhabits a rich star field. Look hard for the round hazy patch, as you might mistake it for a planetary nebula in the Milky Way rather than a galaxy located some 70 million light-years beyond it.

NGC 2559 is found in Puppis, a southern constellation with diverse deep-sky wonders. The most well known are two open clusters, M46 and M93. Located about 8° southwest of M93 in a rich starfield, NGC 2559 is an impressive magnitude 10.9 barred spiral (SBbc). It is twice as long as it is wide, with a bright reddish field star flanking one edge. It's not the only bright galaxy in the area, either. Two degrees north lies the more open SBb-type galaxy **NGC 2566**, an 11th-magnitude target of about the same size.

What about the lord of the winter sky? Does Orion hold any extragalactic wonders? If you've got a telescope of 12 inches or larger, try to find **NGC 2119**, located about 4.5° north of Betelgeuse. At magnitude 13.6, it's one of the faintest targets in this article. A highly elongated elliptical galaxy, NGC 2119 is especially noteworthy because of the constellation in which it lies. Capturing it allows you to say, "I observed the most distant object in Orion!"

If you are looking for galaxies to love in all the wrong places, among the rich star fields of the Milky Way's galactic plane, this list provides you a sampler. You can tackle them throughout the year while observing more ordinary objects, like clusters and nebulae. But for galaxy aficionados, the dare of looking beyond the usual suspects is the only excuse you need to jazz up any observing session.

Alan Goldstein *has contributed to* Astronomy *since 1981 and has been observing since 1973. He also recently published his first juvenile fantasy novel.*

Astronomy magazine 2021 Star Products

Our 11th annual STAR PRODUCTS

by Phil Harrington

This year marks the 11th time we have examined the universe of astronomical products to find some of the best telescopes, binoculars, and accessories available. Whether you are a veteran observer or a brand-new stargazer, you'll doubtlessly find items of interest in our 2021 Star Products. Enjoy our preview of these 35 outstanding entries, presented in alphabetical order by manufacturer.

Phil Harrington *is a contributing editor of* Astronomy *as well as a dedicated equipment collector.*

1 APM HDC XWA 13mm eyepiece

From Saarbrücken, Germany, comes APM Telescopes' new 13mm "x-treme" wide-angle eyepiece. With nine fully multicoated lens elements set in six groups, fully blackened lens edges and spacers, 13mm eye relief, and a cavernous 100° apparent field of view, the HDC XWA will whisk viewers away on a true star trek. The skirted barrel is designed to fit both 1.25" and 2" focusers.

269,00 euros • apm-telescopes.de

2 APM-203 triplet APO refractor

Boasting multicoated, triplet air gap ED APO lenses, the new 8-inch APM-203 f/7 promises images of the Moon, planets, and deep-sky objects that are high in contrast and free of chromatic aberration. The design is just as adept for visual observing as it is for photography, thanks to the standard 2.7" focuser, which makes it easy to attach camera adapters as well as stepdown adapters for star diagonals and eyepieces. The sleek white aluminum tube comes with rotatable tube rings and a Losmandy-style dovetail mounting plate. All this fits into an included aluminum carrying case. Optional upgrades include a Starlight Instruments 3.5" Feather Touch focuser and a carbon-fiber tube.

23,900 euros • apm-telescopes.de

3 Armstrong Metalcrafts Miniature Inner Planet Orrery

Where art meets science: Armstrong Metalcrafts produces some amazingly intricate mechanical devices, including this orrery of the inner solar system. An orrery is a mechanical model that demonstrates the relative positions and motions of the planets orbiting our Sun. This miniature system, measuring just 4 inches (10 centimeters) across, puts the planets in the palm of your hand. A simple turn of a knob on the bottom will make to-scale models of Mercury, Venus, Earth, and Mars orbit around the Sun, and the Moon orbit around Earth. Underneath, an ecliptic plate displays the months, along with the zodiacal constellations and symbols.

$495 • armstrongmetalcrafts.com

5 Blandin Technical EQT-150SC equatorial platform

Equatorial platforms smoothly move a Dobsonian telescope in time with the sky. Blandin Technical's Crossbow EQT-150SC equatorial platform weighs as little as 14 pounds (6.4 kilograms) and can support telescopes weighing up to 225 pounds (102 kg). Secure it to the base of the Dob and it will track the sky effortlessly for up to an hour before the platform needs resetting. Amazingly, it runs on just two AAA batteries that are stated to last 15+ hours.

$1,250 • blandinequatorialplatforms.com

4 Atik Cameras Apx60 CMOS camera

From Norwich, England, Atik is known for producing exceptional astrocameras. Their latest and most advanced is the Apx60, which features Sony's monochromatic IMX455 full-frame CMOS sensor, ideal for large-format, wide-field imaging. The sensor has 61.17 megapixels at 3.76 microns each. The camera's design promises low noise and efficient cooling for prolonged, continuous exposures. The cylindrical Apx60 weighs just 2.2 pounds (1 kilogram) and measures 3.5 by 6 inches (89 by 152 millimeters).

$4,400* • atik-cameras.com

*Preproduction price; sales price subject to change

6 BuckeyeStargazer desiccant caps

You should never put away a damp telescope, as any moisture can leave water stains on optics and damage delicate coatings. BuckeyeStargazer's desiccant caps offer a simple solution to the problem: Each cap comes with a water-absorbing pack that can be easily recharged in a microwave oven. They are available in several versions that fit into 1.25" and 2" focusers and feature an O-ring to better seal any gaps. Custom sizes are also available upon request.

$23 (1.25"); $26-$30 (2") • buckeyestargazer.net

7 Celestron NexImage Burst Color imager

If you marvel at spectacular images of the solar system in every issue of *Astronomy* and would like to try your hand at taking your own without spending a fortune, the NexImage Burst Color by Celestron is a good introductory imager. The compact Burst Color weighs only 2 ounces (57 grams), so certainly will not adversely affect the balance of a telescope. Inside, Aptina's 1.2-megapixel AR0132 CMOS imaging sensor can capture over 120 frames per second when subframed or 30 frames per second at full frame. The included software automatically removes frames affected by poor atmospheric conditions, leaving only the sharpest shots.

$199.95 • celestron.com

8 Celestron Ultima Edge 15mm Flat Field eyepiece

Celestron's revamped line of Ultima eyepieces, now called Ultima Edge, includes five focal lengths ranging from 10mm to 30mm. The 15mm is a nice midrange eyepiece with an apparent field of view measuring 65° and 16mm of eye relief, thanks to its fully multi-coated, eight-element lens design. The black-anodized aluminum barrel fits standard 1.25" focusers and is threaded to accept filters. The housing also includes a molded rubber grip ring for more secure handling, as well as a fold-down rubber eyecup.

$129.95 • celestron.com

10 DayStar SR-127-QT H-Alpha refractor

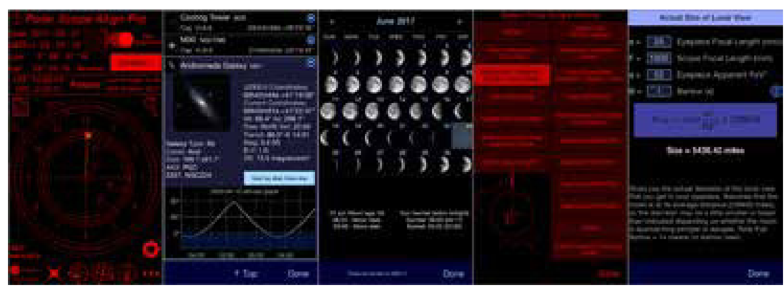
Last year, DayStar introduced a new flagship to their line of solar telescopes. The SR-127-QT is a 5-inch f/21 achromatic refractor that is optimized for Hydrogen-alpha (H-α) viewing. Three models are available: One is intended for viewing prominences, a second for observing the chromosphere, and a third can be custom designed for a specific wavelength between 0.2 and 0.8 angstroms. The scope's carbon-fiber tube measures 31.1 inches (79 cm) long with the dew shield retracted. With the standard mount rings, it weighs only 13.6 pounds (6.2 kg). The H-α filter operates on a 12-volt DC current, so it can be powered by a user-supplied portable battery. An optional focal reducer cuts the focal length from 2,667mm to 1,355mm.

$5,995 (prominence); $7,995 (chromosphere) • daystarfilters.com

9 CFF Telescopes 135mm APO refractor

Although not as well known in the U.S. as some other brands, CFF Telescopes are highly regarded in Europe, where they are designed and manufactured. The 5.3-inch f/6.7 refractor 135mm features oil-spaced design with a core element of Ohara S-FPL53 glass, famous for its outstanding performance. Images are brought into sharp focus with the included 3.5" dual-speed rack-and-pinion focuser from Starlight Instruments. Other standard features include a removable dew shield, CNC mounting rings and dovetail plate, and a transport case.

6,519 euros • cfftelescopes.eu



11 Dimitrios Kechagias' Polar Scope Align Pro app

While many telescopes feature advanced go-to systems that auto-steer to selected targets, others still require manual navigation. After installing Dimitrios Kechagias' Polar Scope Align Pro app on your iPhone, you can use the phone's digital compass to find dim targets. If you're worried about your compass' calibration, the app's "hop to" function can be used to calibrate the app. You can then use the "push to" function to push your scope toward the target.

$2.99 • iOS store

12 Educational Insights GeoSafari Jr. Kidnoculars

The 2x35 non-prismatic Kidnoculars are a great way to introduce the youngest stargazers to binocular viewing. True, the plastic lenses do not produce the quality images we would expect from adult-sized binoculars. But that's not what these are about. Kidnoculars are a teaching tool. Their biggest benefit is helping young children learn how to hold and view through binoculars. The large, soft rubber eyecup is designed to surround the child's eyes completely, while an integrated nose cutout makes it easy to position them perfectly. The low magnification also helps kids aim without a lot of image shake.

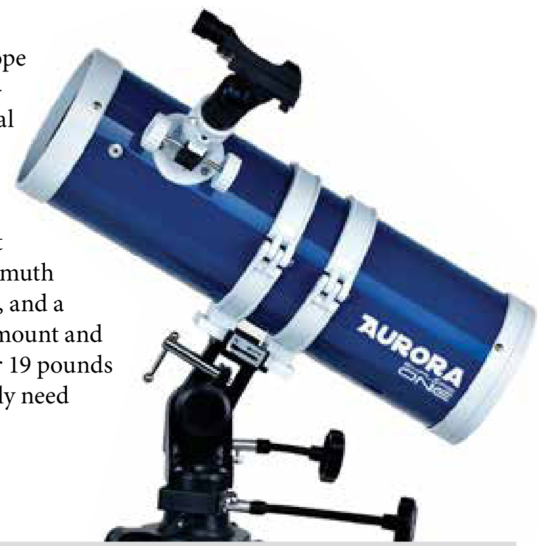
$14.99 • educationalinsights.com

13 Explore Scientific BT-120 SF Large Binoculars

Looking for big binoculars? Explore Scientific's BT-120 SF may be just the model you want. The BT-120s feature a pair of 4.7-inch lenses mounted in a magnesium housing that is sealed and filled with nitrogen. At the other end, Porro-prism assemblies are tilted at 45° for more comfortable sky viewing. The BT-120s come equipped with two 20mm eyepieces with 62° apparent fields of view. The eyepieces are interchangeable and may be substituted with any eyepiece pair with a plug-in diameter of 1.25 inches (31.7 mm). The sleek, glossy white tube also includes an integrated handle for easy carrying. A sturdy tripod, sold separately, is highly recommended.

$2,349.99 • **explorescientificusa.com**

14 Explore Scientific Explore One Aurora 114mm Reflector Telescope



The 4.5-inch f/4.4 Explore One 114mm Reflector is a great telescope for children and young adults getting into observing. It offers a focal length of 500mm and comes complete with everything a beginner needs, including 20x and 52x Plössl eyepieces, a red dot finder, an easy-to-use altitude-azimuth mount with slow motion controls, and a fully adjustable tripod. With the mount and tripod, this scope weighs just over 19 pounds (8.6 kg), meaning a child will likely need some help moving it.

$149.99 • **explorescientificusa.com**

15 Explore Scientific Two-Room Pop-Up Go Observatory Tent

Earlier this year, Explore Scientific introduced their Two-Room Pop-Up Go Observatory Tent, designed to shelter telescopes and observers from stray light, wind, dust, and rain. The tent's pop-up design makes setup simple. Release the storage strap and each side pops up from its pack. Next, connect the two observatory rooms with a Velcro seam, and stake the tent to the ground. Each room measures 5 by 5 by 5 feet (1.5 by 1.5 by 1.5 meters) with wind break walls that stand 6 feet (1.8 m) high. The tent is made of blackout-coated fabric that is both waterproof and offers UV protection. A removable fly is also included for when the tent is not in use or to guard against rain.

$279.99 • **explorescientificusa.com**

16 iOptron iGuider autoguiding system

Known for innovative products, iOptron offers the iGuider self-contained autoguiding system, which comprises a 30mm f/4 achromatic guide scope coupled to an iGuider 1 camera. The compact autoguider weighs just 7 ounces (200 g), significantly smaller and lighter than conventional guide scopes. While designed to fit iOptron's CEM26 and GEM28 mounts without an adapter, the iGuider can also mount to any scope with a standard finder scope dovetail base. The camera connects to any computer running ASCOM planetarium software.

$218 • **ioptron.com**

17 LensPen lens cleaner

Whether you use a telescope, binoculars, or a camera, you should have a LensPen nearby to deal with the inevitable smudges that come from touching an optical surface with your finger or eyelashes. Several versions are available. The original full-size LensPen measures 4.3 inches (11 cm) long. At one end is a round cleaning tip that uses a special non-liquid cleaning element that will never dry out. The tip is slightly concave to match the convex shape of most lenses. At the opposite end is a retractable brush for removing dust particles. Both are safe to use on all optical surfaces.

$12.95 • lenspen.com

18 My Science Shop Antique Star Chart Set: The Four Seasons

Collectors of vintage astronomy books will immediately recognize the name Elijah Hinsdale Burritt as the author of the 1835 classic *The Geography of the Heavens*. It was a two-part effort: part textbook and part star atlas. For the latter, he created a set of artistic representations of the entire sky. Now, you can display reproductions of his antique star charts featuring all four Northern Hemisphere seasonal skies. Each chart measures 22½ inches x 21 5/16 inches (57.2 cm x 56.7 cm) in size and is suitable for framing.

$59.99 • myscienceshop.com

19 My Science Shop *Astronomy* magazine: The 5-Year Collection 2016-2020

It's great to look forward to each monthly issue of *Astronomy* magazine, with its wealth of information and amazing images. Wouldn't it be nice to have them all in one easily searchable location? Every issue published between 2016 and 2020, including four special issues, is now available on a single DVD that will run only on Windows and Mac computers. There is no better way to relive the 2017 Great American Eclipse, the 50th anniversary of the Apollo 11 Moon landing, the New Horizons Pluto flyby, and the discovery of gravitational waves than with this DVD.

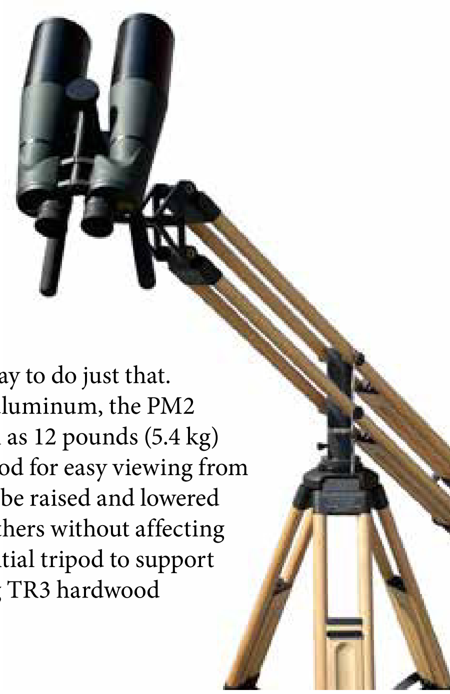
$29.95 • myscienceshop.com

20 nPAE Rotating Eyepiece Turret

Switching between eyepieces or between an eyepiece and a camera at night, all while not bumping the aim of a telescope, can be a daunting task. This rotating eyepiece turret from nPAE makes that challenge a thing of the past. Honed from aircraft-grade aluminum and then red-anodized, nPAE's Rotating Eyepiece Turret has three ports for 1.25" eyepieces and another three for 2" eyepieces. The spacing is wide enough to simultaneously accept DSLR cameras and binoviewers. There are also three dedicated slots for 2-inch filters that allow all components attached to the turret to share the same filter.

£995.00 • npae.net

21 Oberwerk PM2 Parallelogram Mount



One of the challenges to observing with two eyes instead of one is holding binoculars — especially giant binoculars — steady enough to enjoy the view. The PM2 Parallelogram Mount from Oberwerk is the perfect way to do just that. Made from maple, stainless steel, and aluminum, the PM2 will hoist binoculars weighing as much as 12 pounds (5.4 kg) skyward, offsetting them from the tripod for easy viewing from horizon to zenith. The binoculars may be raised and lowered effortlessly for sharing the view with others without affecting the aim. You will need to add a substantial tripod to support the PM2, such as Oberwerk's matching TR3 hardwood tripod.

$629.95 • oberwerk.com

22 Omegon veLOX 287 C Color planetary imager

Designed with planetary, lunar, and solar imaging — as well as autoguiding — in mind, Omegon's veLOX 287 C Color imager packs a lot of features into a small and reasonably priced package. The imager's bronze-anodized aluminum body is shaped like a 1.25" eyepiece, measuring just 2.8 inches (7.1 cm) long and weighing 3.2 ounces (90 g) without the supplied USB cable. On the back are ports for the guiding and USB cables. Inside lies Sony's IMX287 CMOS sensor, with 728x544 pixels. The imager can capture up to 520 images per second at full resolution, and then process them using the supplied AstroPhotoCapture software to generate the sharpest possible results.

$434 • **omegon.eu**

23 Orion Right-Angle 1X-2X Viewer for Polar Scopes

If you own a portable German equatorial mount with a built-in polar-alignment scope, then you know what a chore it can be to sight through that scope while aligning the axis with the celestial pole. Your back and neck will appreciate Orion's Right-Angle 1X-2X Viewer for Polar Scopes. The viewer slips over the eyepiece end of any 25mm- to 30mm-diameter polar scope. An internal Amici prism produces the same image orientation as the polar scope, while turning a helical focus ring sharpens the view. After alignment is set initially, slide the magnification setting from 1x to 2x for a closer inspection.

$119.99 • **telescope.com**

24 Radian Telescopes Raptor 61 APO refractor

Radian Telescopes recently added to their lineup the Raptor 61, a 2.4-inch f/4.5 apochromatic refractor. Inside the red-accented glossy black tube lies the heart of the Raptor 61, an apochromatic triplet objective made from premium glass. Multicoatings result in sharp, contrasty images free from chromatic aberration and reflections. The telescope comes standard with a sturdy 2.5" dual-speed rack-and-pinion focuser, a filter vault that allows easy swapping of 2-inch filters, a 360° rotator, a padded-insert travel backpack, and unique hexagonal mounting rings for attaching several different accessories simultaneously.

$999.99 • **radiantelescopes.com**

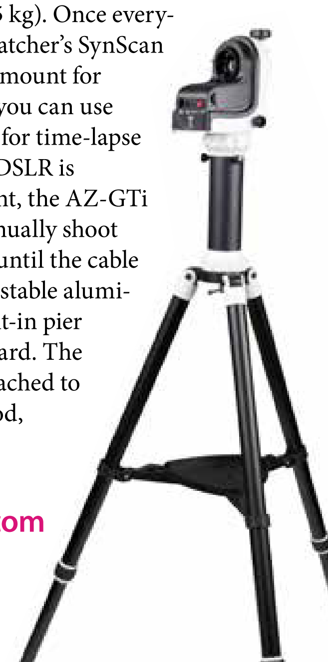
25 Rainbow Astro RST-135 Weightless Mount

As the British TV show *Monty Python's Flying Circus* used to say, "And now for something completely different." Although the RST-135 Weightless Mount is not weightless (it weighs 7.3 pounds [3.3 kg]), it is lacking the cumbersome counterweight seen on the lookalike German equatorial mounts. To pull this off, the RST-135 uses a strain-wave gear system to produce a high-ratio gearbox in a compact space. This lets the mount carry payloads up to 30 pounds (13.5 kg) without a counterweight. The RST-135 also includes built-in Wi-Fi and GPS for cordless operation.

$3,895 • **rainbowastro.com**

26 Sky-Watcher AZ-GTi Mount

Designed to be portable, yet include the most wanted features like go-to alignment, built-in Wi-Fi control, and video time-lapse capability, Sky-Watcher's AZ-GTi altitude-azimuth mount is a great choice for short-tubed telescopes weighing up to 11 pounds (5 kg). Once everything is set up, Sky-Watcher's SynScan Pro app can align the mount for celestial tracking. Or you can use the SynScan PTZ app for time-lapse photography. Once a DSLR is plugged into the mount, the AZ-GTi will trigger it to continually shoot 60-second exposures until the cable is unplugged. An adjustable aluminum tripod and a built-in pier extension come standard. The mount can also be attached to nearly any photo tripod, if preferred.



$400 • **skywatcherusa.com**

27 SpicaEyes 16-inch SlipStream Dobsonian

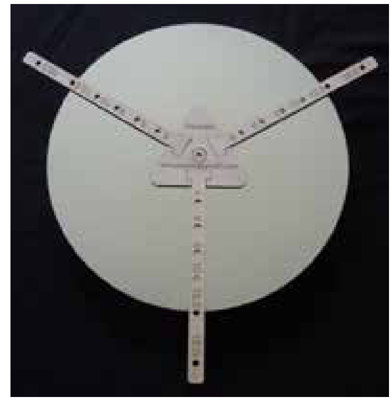
From Equatorial Platforms comes a line of 16-inch and larger SpicaEyes reflectors. The featured 16-inch aperture uses optics crafted by Lightholder Optics, as do the 18- and 20-inch models. The larger apertures use mirrors from Kennedy Optics. All feature aluminum truss optical assemblies perched on Dobsonian-style GoTo SlipStream drive systems. The SlipStream drive includes slip clutches on both axes, letting you move the scope manually or with the wireless hand control. Once a target is in view, the tracking platform keeps the telescope perfectly centered on it.

$19,500 • **equatorialplatforms.com**

28 Stellarvue SVX102D refractor

With a 4-inch f/7 fully multicoated doublet objective made with super low-dispersion and lanthanum elements, the new SVX102D refractor from Stellarvue promises outstanding optical performance. The oversized Feather Touch focuser from Starlight Instruments easily brings images into sharp focus. The glossy white aluminum tube is fully baffled and painted ultraflat black inside to prevent spurious light from slipping in and spoiling the view. A retractable dew shield, CNC-machined mounting rings, and a finder scope dovetail base round out the package.

$1,895 • **stellarvue.com**



30 Telescope Mirror Alignment Tool

Made of thin Baltic Birch hardwood, the Telescope Mirror Alignment Tool, or Telmat, is an easy way to precisely mark the center of a Newtonian reflector's primary mirror, greatly simplifying collimation. Created by retired optical engineer Bob Schalck and his son Jonathan Schalck, the Telmat fits standard-size mirrors 4 to 16 inches (10 to 40 cm) in diameter. (Larger sizes by request.) Lay the Telmat on the mirror so that the three viewing holes matching its diameter align with the mirror's outside edge. Once everything is lined up, mark the mirror's center with a small dot using an indelible marker, or by inserting a punch-hole reinforcement ring through the Telmat's central hole. Note that you won't be able to Google this company.

$19.95 • **telmatsales@gmail.com**

29 Takahashi Epsilon E-160ED reflector

The 6.3-inch f/3.3 Epsilon E-160ED reflector is the newest member of Takahashi's family of Newtonians designed specifically for astrophotography. The fast optical system consists of a hyperbolic, concave primary mirror and a two-element ED corrector lens to eliminate spherical aberration and coma, which are common image-spoiling aberrations. Together, the optics produce sharp star images across the field, making the Epsilon E-160ED perfect for full-frame sensors. Cameras can be attached directly to the oversized, rotatable focuser. The mount, camera, tripod, and finder are sold separately.

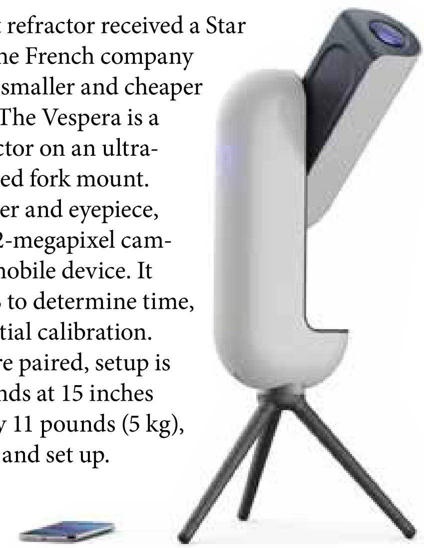
$3,960 • **takahashiamerica.com**

31 Tele Vue DIOPTRX astigmatism corrector

Those who have astigmatism are usually forced to wear their glasses while observing, preventing them from enjoying the wide fields available with many of today's premium eyepieces. But the creator of many of those premium eyepieces, Tele Vue, has a solution. The fully multicoated DIOPTRX attaches to the top of more than 20 long eye-relief Tele Vue eyepieces. Once in place, the DIOPTRX can be rotated to compensate for the astigmatic axis angle and get the sharpest possible full-field view. Select the diopter that corresponds with the cylinder reading on your eyeglass prescription.

$105 (0.25-2.50 diopters); $122 (3-3.50 diopters) • televue.com

32 Vaonis Vespera smart telescope



Last year, the Stellina smart refractor received a Star Product award. This year, the French company Vaonis is back again with a smaller and cheaper version called the Vespera. The Vespera is a 2-inch f/4 achromatic refractor on an ultra-modern, computer-controlled fork mount. Rather than include a focuser and eyepiece, the Vespera uses a built-in 2-megapixel camera to display images on a mobile device. It uses that same device's GPS to determine time, date, and location for its initial calibration. That means once the two are paired, setup is automatic. The Vespera stands at 15 inches (40 cm) tall and weighs only 11 pounds (5 kg), making it easy to transport and set up.

1,499 euros • vaonis.com

33 Vixen 2.1×42 Constellation Binoculars

Ever want to have super eyes? Ultralow-power wide-field binoculars like Vixen's 2.1×42 Constellation Binoculars are becoming increasingly popular for that reason. These binoculars include five multicoated elements designed to take in 25° of sky in a single view. This means that full constellations fit into the field. The binoculars also increase the visibility of stars by more than a full magnitude over the eye alone, and enhance the contrast of the Milky Way.

$450 • vixenoptics.com

34 Vixen Polarie U Star Tracker

Vixen has recently released an updated version of their popular Polarie camera tracker. The Polarie U is a compact, self-contained design that — once aligned to the celestial pole using the integrated alignment scope — will effortlessly track a camera across the sky. The companion app allows you to link your smartphone to the Polarie U's motion and camera shutter release. This makes setting up time-lapse and interval photography easy, producing dramatic results.

$980 • vixenoptics.com

35 William Optics Fluorostar 91 refractor

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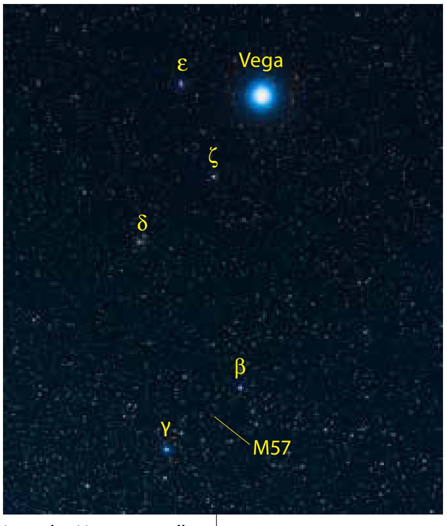
The cosmic Harp

Stellar pairs and a planetary nebula await in Lyra.



Lyra the Harp, a small constellation in the northern sky, is easily recognizable as a parallelogram of four stars located near the very bright star Vega. Visible just to the left (east) of Vega in this image shines the "Double-Double" star Epsilon (ε) Lyrae, while the tiny Ring Nebula (M57) hides about halfway between the bottommost stars of Lyra's parallelogram. ALAN DYER

BY GLENN CHAPLE

Glenn has been an avid observer since a friend showed him Saturn through a small backyard scope in 1963.

The most important rule for any hobby, backyard astronomy included, is to have fun. That's why when I find myself getting overly wrapped up in "serious" observing, I devote an entire evening to relaxed skygazing with my 2.4-inch f/12 refractor.

Last autumn, I did just this, touring the constellation Lyra the Harp with my modest scope. Though Lyra is typically associated with summer evenings, its position high overhead makes it awkward to observe with refracting telescopes at that time of year. The small constellation is still visible in October, though, comfortably positioned halfway up in the western sky after sunset.

During my fall tour of the Harp, I started with its brightest star, Vega (Alpha [α] Lyrae). At magnitude 0.03, it's the fifth brightest star in the night sky. Through the eyepiece, Vega sparkled like a diamond, exhibiting its A0 spectral type. An optical double star, Vega has a 9.5-magnitude line-of-sight partner 83.7" to its south. Normally, a pair this wide is easily split with a small scope. But Vega is some 6,000 times brighter than its companion, so even with high power, I couldn't spot Vega's partner.

Vega sparkled like a diamond.

The distinguishing feature of Lyra is a parallelogram formed by the stars Beta (β), Gamma (γ), Delta (δ), and Zeta (ζ) Lyrae. Beta and Zeta, the westernmost of the four, are both wide and easy doubles. Beta is a noted eclipsing binary that varies between magnitude 3.3 and 4.4 over a 13-day cycle, and its magnitude 6.7 partner sits a comfortable 45.7" away. Zeta is similarly wide, consisting of magnitude 4.3 and 5.6 components separated by 43.7". Both pairs were nicely split at 23x.

Up next was Epsilon (ε) Lyrae, the celebrated "Double-Double." Low magnification revealed two stars, Epsilon^1 and Epsilon^2 Lyrae, of magnitudes 4.7 and 4.6, respectively. They were 210" apart, a separation that can be breached by the unaided eye if you have keen vision, or by ordinary binoculars if you don't. Each of these stars is in its own tight binary, too. Epsilon^1 consists of magnitude 5.2 and 6.1 components separated by some 2.1", while Epsilon^2 is a pairing of near twins (magnitudes 5.3 and 5.4) separated by 2.3". I needed 117x — which is about the maximum useful magnification for a 2.4-inch refractor — to split these close pairs.

Lyra also holds a second double-double, this one located some 7° southeast of Epsilon Lyrae. It's comprised of two more double stars: Struve 2470 (magnitudes 7.0 and 8.4, separation 13.8") and Struve 2474 (magnitudes 6.8 and 7.9, separation 16.0"). This pair of pairs will literally give you double vision; they are not only similar in magnitude and separation, but also in position angle, with both companions sitting roughly west of their primaries.

After exploring Lyra's main multi-star systems, I returned to the parallelogram, focusing on the wide optical pair Delta^1 and Delta^2 Lyrae. These stellar gems are part of a loose open cluster named Stephenson 1. Consisting of a few dozen members, the group lies about 1,200 light-years away. Rob Datsko of Highlands Ranch, Colorado, notes that the cluster is home to a strikingly symmetrical triangle-within-a-triangle asterism. Delta^2 (magnitude 4.2), Delta^1 (magnitude 5.6), and HIP 92769 (magnitude 7.6) form a wide outer triangle encapsulating an inner, nearly equilateral triangle of 8th magnitude stars. Phil Harrington also mentioned this grouping in his September 2019 Binocular Universe column. Even at 70x, I found Datsko's Double Triangle to be an eye-pleasing sight through my 2.4-inch scope.

Traveling twice as far into space (2,300 light-years), I next set my sight on Lyra's most celebrated deep-sky object: the planetary nebula M57, also known as the Ring Nebula. Like most planetaries, it's rather small (roughly 60" by 90") and faint (9th magnitude). Fortunately, M57 is located almost midway between Beta and Gamma Lyrae. Because the Ring Nebula appears nearly starlike at low magnification, I scanned the area with medium power until I came across an out-of-focus "star." Upping the magnification to 70x, I was able to make out M57's fuzzy oval. Years ago, I caught some backlash by stating the Ring is only visible with scopes of 6-inch aperture or larger. I've since seen it with smaller scopes, but not with my 2.4-inch. How about you?

Finally, I tracked down Lyra's other Messier object: the often overlooked globular cluster M56. This object is frequently glossed over because it's located in an out-of-the-way location, it's relatively faint (magnitude 8.3), and it's quite small (only the bright 3'-diameter central region is visible in small scopes). To find it, I aimed toward a spot roughly midway between Gamma Lyrae and Albireo (Beta Cygni), searching the area with the same technique I used to locate M57. Visually, M56 was unimpressive, but knowing that the puffball greeting my eye was actually a swarm of tens of thousands of stars some 33,000 light-years away heightened the "wow" factor.

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: A tale of two Saturns. Clear skies!

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Astronomy for kids

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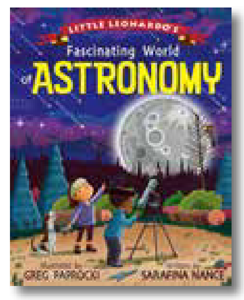
Written by astrophysicist Sarafina Nance, *Little Leonardo's Fascinating World of Astronomy* (Gibbs Smith, 2021) introduces young readers ages 4 to 8 to the universe. Illustrations by Greg Paprocki accompany topics from bizarre exoplanets to the reason why Earth only has one moon when Jupiter has so many. The jacketless hardcover book is 24 pages long.



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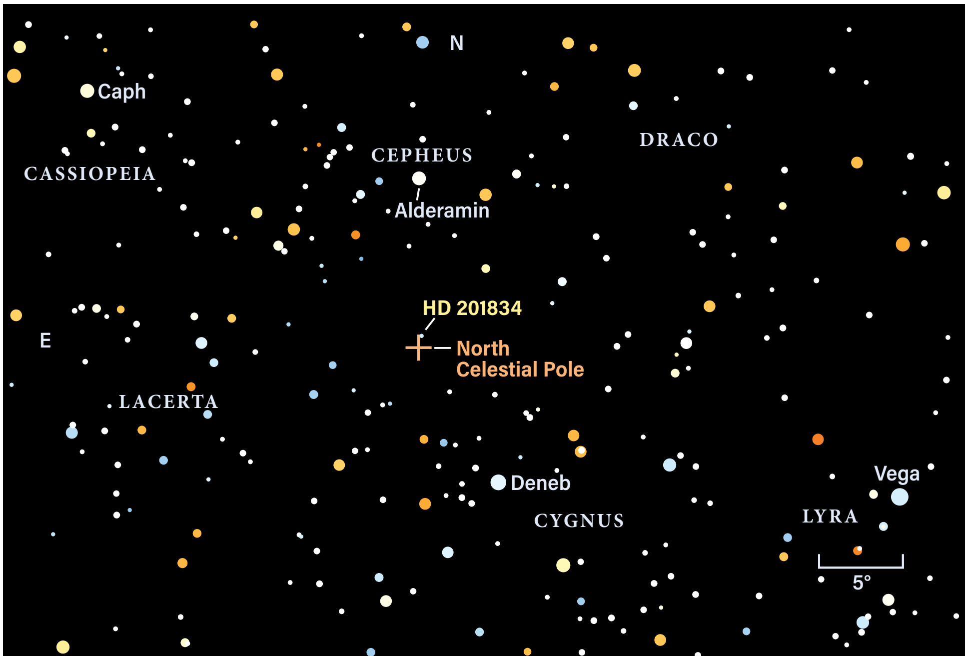


The star HD 201834 lies within about 40' of Mars' North Celestial Pole. That's about as far as Polaris is from Earth's North Pole, but HD 201834 is nearly 40 times fainter — a tough naked-eye target for future humans on Mars. *ASTRONOMY*: ROEN KELLY

Martian North Star

Q | WITH ALL THE PROGRESS TOWARD PUTTING A HUMAN ON MARS, I WAS WONDERING: WHAT IS THE NORTH STAR FOR SOMEONE ON MARS?

Ralph Winrich
Dunkirk, Wisconsin

A | On Earth, the North Star is defined as the star toward which Earth's north rotational pole points. Currently, that star is 2nd-magnitude Polaris, located in Ursa Minor — although it's worth noting that Earth's north rotational pole, also called the North Celestial Pole, doesn't point *exactly* to this star. Rather, Polaris is about 40' from the North Celestial Pole, but because it's relatively bright and very close to the pole, we call it the North Star.

So, what about Mars' north rotational pole? It turns out that on Mars, the North Celestial Pole falls in a region of the sky located in the constellation Cygnus the Swan. (Mars is close enough to Earth that the sky appears virtually identical to that on our planet, with all the stars and constellations in the same configurations.) Just like on Earth, there's no star directly above the pole, but again within about 40' is the magnitude 5.8 star HD 201834. But such a faint star, which is nearly 40 times dimmer than Polaris, would be barely visible — if at all — even to those with extremely good eyesight under extremely good conditions. So, for all intents and purposes, humans on Mars would not have a bright, easily visible North Star to guide them. Under ideal conditions or with binoculars or a telescope, however, they could use HD 201834 as their martian North Star.

Alison Klesman
Senior Associate Editor

Q | CAN A BLACK HOLE FORM WITHOUT A PARENT STAR?

Rich Livitski
Seal Beach, California

A | A few different kinds of black holes exist. First are stellar-mass black holes, which can range from 3.3 to 100 times the mass of the Sun. These are the lowest-mass black holes that we've observed. One way these black holes form is when the most massive stars in the universe reach the end of their life. Alternatively, a neutron star can become a black hole if it either accretes enough material from a companion star or merges with another star, pushing it over the neutron star mass limit.

But stellar-mass black holes are on the low-mass side of the spectrum. On the heavier side are supermassive black holes. These heavyweights lie at the hearts of most

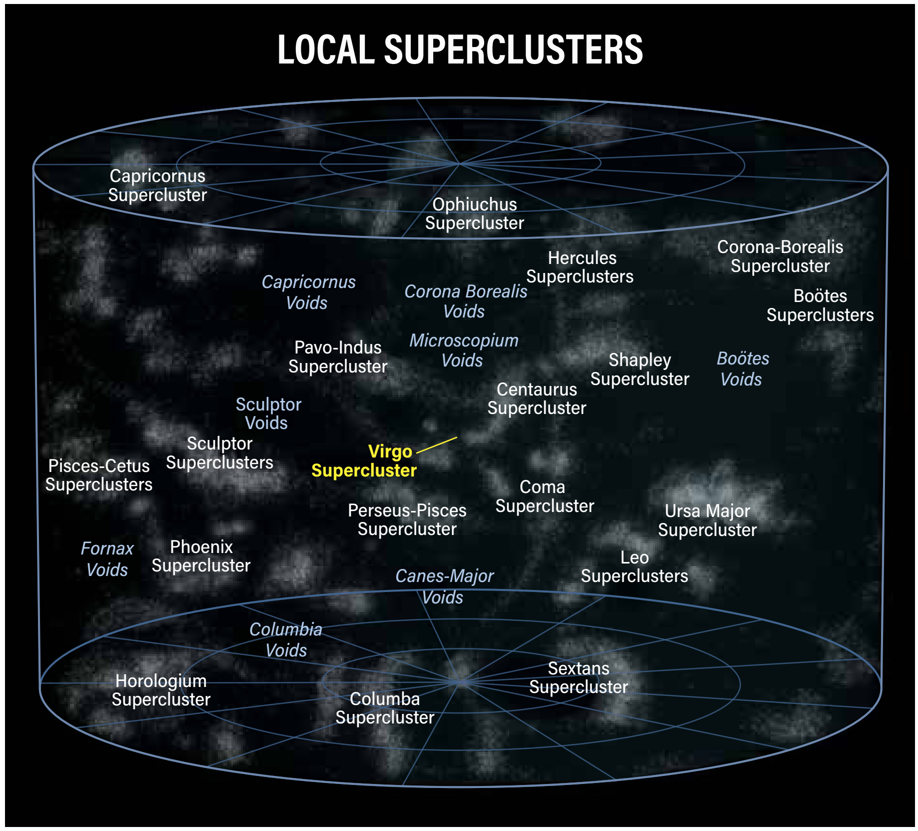
Blazing at a time when the universe was a mere 770 million years old, ULAS J1120+0641 (shown in this artist's concept) hosts a supermassive black hole 2 billion times the mass of the Sun. Researchers are working to explain how galaxies like this grew black holes so large so fast in the early universe. ESO/M. KORNMESSER

galaxies and weigh millions to billions of solar masses. Between them lie intermediate-mass black holes — ranging from 100 to 1 million solar masses.

Although researchers have the basic formation of stellar-mass black holes down, supermassive black holes have posed a problem because scientists don't yet understand how they grew so big so fast in the early universe. While it's true that stellar-mass black holes could merge and create a supermassive one, there just isn't enough time for stars to die in great enough amounts to account for the behemoths seen in the cosmos' early galaxies.

But there is a starless route that could lead to these monsters, one that was only possible in the early universe. So-called direct-collapse black holes wouldn't need to wait for a star to die to form them. Instead, clusters of early galaxies could influence each other. If you have two or more early galaxies near each other, one may undergo rapid star formation. This heats up the gas within a neighboring galaxy, preventing that gas from fragmenting into clumps that would eventually become stars. This monolith of gas is then overcome by gravity and collapses into an intermediate-mass black hole. Such events could occur throughout the young galaxy, forming a few intermediate-mass black holes that eventually coalesce at the center of the galaxy, creating a supermassive black hole.

Caitlyn Buongiorno
Associate Editor



Superclusters such as those shown on this map of the local universe lie along the webbing of the cosmos. Between clusters are spaces with few or no galaxies. By studying voids, researchers hope to gain insight into dark energy — the mysterious force driving the universe's expansion. ASTRONOMY: ROEN KELLY, AFTER ANDREW Z. COLVIN

Q | I'VE SEEN IT STATED THAT GIANT VOIDS EXIST BETWEEN GROUPS OF GALAXIES. IS DARK ENERGY, THE MYSTERIOUS FORCE DRIVING GALAXIES AWAY FROM ONE ANOTHER, CREATING THESE VAST VOIDS OF SPACE?

Keith Thompson
Warrington, England

A | To understand the forces at play in the expansion of the universe, it helps to rewind all the way back to the Big Bang, when the universe burst forth from an extremely hot and dense point. The cosmos then underwent inflation, when it quickly but briefly ballooned outward. Matter and energy (there were no galaxies or stars yet) were pushed in all directions, causing the universe to grow at a rate faster than the speed of light. Eventually, this inflationary period ended, but the universe didn't stop growing.

Imagining this expansion can be a bit tricky. There are a few common explanations that people use, and my favorite is raisin bread. Imagine the cosmos as raisin bread dough baking in the oven. As the dough rises, the raisins move farther apart — but they themselves aren't moving. Instead, the expanding dough is carrying them apart. The same is true for the universe: As it expands, galaxies are pulled away from each other, but they aren't moving — space itself is. And up until 1998, we thought leftover energy from the Big Bang was the only thing driving this expansion and gravity would eventually slow it down. Instead, the opposite is happening, thanks to dark energy.

As for the voids in between galaxies, you can think of the universe as a vast web. The silk strands are filled with large clusters of galaxies, called superclusters, and the spaces in between the webbing are voids with very few or no galaxies. Researchers believe the seeds for these voids and clusters were planted at the very beginning of the universe, when it was much smaller and therefore most sensitive to any fluctuations in density. So while dark energy did not create these voids, it had a great influence on how they evolved and grew over time. That means voids are a powerful way to study dark energy, as they magnify cosmological differences felt in the early universe. By studying their evolution, scientists hope to gain insight into the nature of dark energy.

Caitlyn Buongiorno
Associate Editor

SEND US YOUR QUESTIONS

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Cosmic portraits

1. RUSTY SPIRAL
M88 is a gorgeous spiral galaxy in Coma Berenices, strewn with fine dust lanes surrounding an active nucleus — a black hole with the mass of 80 million Suns, gorging itself on material. Also visible at the far right is the small elliptical dwarf galaxy PGC 169494. *▪ Adam Block/Mount Lemmon SkyCenter/University of Arizona*

2. RING OF CLUMPS
RCW 58 is a faint ring-shaped nebula in Carina surrounding a massive Wolf-Rayet star, WR 40. Unlike other wind-blown bubbles around WR stars, the shell of RCW 58 is quite clumpy, making it an ejecta nebula — one thought to contain some material from its progenitor star. *▪ Kfir Simon*

3. GLIDING GULL
The Seagull Nebula occupies the top half of this two-image mosaic, with its glowing head (emission nebula NGC 2327) and graceful wings (which are part of IC 2177). But what caught the photographer's eye in this composition was that it "appears to have a faint reflection in the nebulosity below it." The image was taken with a 4.2-inch refractor and 32 hours of exposure time in the Hubble palette. *▪ Alistair Symon*

4. WINTER WONDERLAND
Orion and the Milky Way tower above the landscape of the Iranian salt desert Dasht-e Lut in this mosaic. The photographer made single exposures at 25 seconds, f/2.2, and ISO 4000, using a portable star tracker. *▪ Amirreza Kamkar*

5. CNIC VIEW
Views of annularity during the solar eclipse of June 10, 2021, were limited to northern Canada, Greenland, and Russia. But this photographer captured a partial eclipse in progress behind the CN Tower in Toronto at 5:50 P.M., roughly 10 minutes after maximum. • ***Felix Zai***

6. MOON OF MANY NAMES
This mashup of eight months of Full Moons captures its journey from a "Micro-Moon" at its apogee on Halloween of 2020 to a "Super Moon" at perigee on May 26, 2021, when it appears about 17 percent larger. Each of the images was taken from Kolkata, India, with a Nikon D5600 and a 600mm zoom lens. • ***Soumyadeep Mukherjee***

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A GALACTIC GEM WORTHY OF A KING

At first glance, NGC 2276 appears to be a classic face-on spiral galaxy. But a closer look shows something is askew. The island universe's galactic bulge of old, yellowish stars sits well off-center, proving that this beauty tilts significantly to our line of sight. And that's just one of NGC 2276's quirks. Notice the bluish glow from the glut of recently formed massive stars on the galaxy's left side. This ongoing burst of star formation results from NGC 2276 plowing through the hot gas pervading its host cluster. The distorted spiral arms on the galaxy's opposite side arise from the gravitational pull of a companion galaxy, NGC 2300, which lies beyond the image's edge. NGC 2276 resides 120 million light-years from Earth in the constellation Cepheus the King. NASA/ESA/STSCI/PAUL SELL (UNIVERSITY OF FLORIDA)


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Eagle Nebula from Bortle class 9 skies (Long Beach, CA)
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